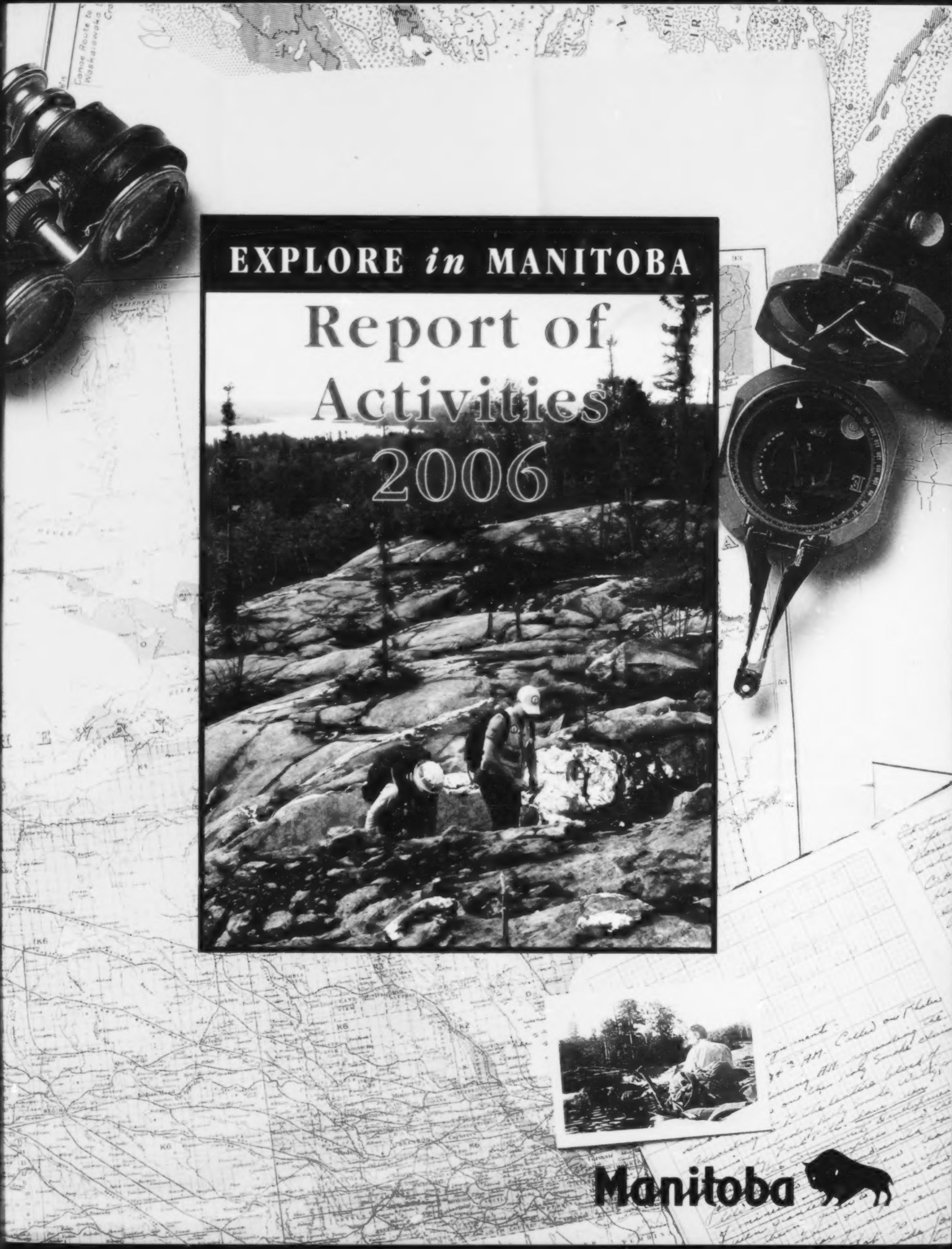

EXPLORE *in* MANITOBA

Report of Activities 2006

Manitoba

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REPORT OF ACTIVITIES
2006

Manitoba Science, Technology, Energy and Mines
Manitoba Geological Survey

Manitoba

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REPORT OF ACTIVITIES 2006

A message from the Minister:

Manitoba's mining industry is thriving with the ongoing record-setting increases in metal prices. Spending on exploration in the province is forecasted to reach an all-time high of $48.8 million in 2006. That's welcome news because exploration for new deposits is essential to the future of mining in Manitoba. But we're not done yet … there is the ongoing challenge to successfully compete against other jurisdictions in a global and intensely competitive mineral investment market.

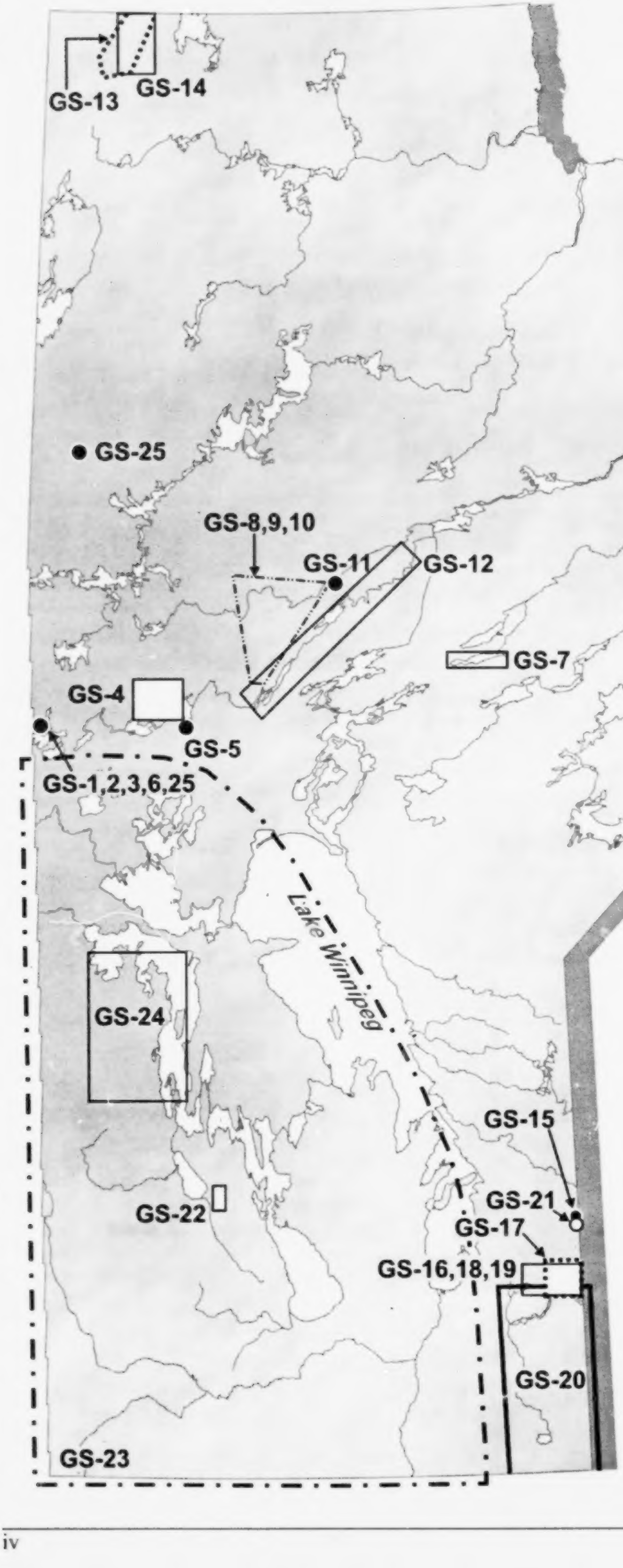
We've met this challenge by developing policies and programs that support exploration in the province. Companies are coming to Manitoba to explore because we offer attractive financial incentives, a stable and effective regulatory framework and ready access to high-quality geoscientific data. According to the 2006 Fraser Institute survey of mining companies, our strategy is working. The survey ranks Manitoba third worldwide for both its mineral policies and geological database.

The *Report of Activities* is just one example of the high-quality data we make available to assist exploration. It summarizes the Manitoba Geological Survey's geoscience investigations from the past year including new field programs, new digital initiatives, and collaborative ventures with the federal government, universities, and the mineral exploration industry.

The *Report of Activities* is released at our Manitoba Mining and Minerals Convention where stakeholders from industry, government, Aboriginal and northern communities, and interest groups, as well as potential investors meet annually to learn more about our mineral wealth. The report is available on our website, on CD and in print to ensure that the latest on Manitoba's geology and mineral resources is readily accessible to everyone.

I invite you to invest in Manitoba … your exploration advantage.

Honourable Jim Rondeau
Minister of Science, Technology, Energy and Mines


HUDSON
BAY
GS-13
GS-14
GS-25
GS-8,9,10
GS-11
GS-12
GS-7
GS-4
GS-5
GS-1,2,3,6,25
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GS-24
GS-15
GS-21
GS-17
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GS-20
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0
100
kilometres

2006

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Introduction

In 2006, the Manitoba Geological Survey (MGS) continued significant in-depth investigations in the Superior Boundary Zone and Thompson Nickel Belt (TNB), the Paleoproterozoic Flin Flon Belt, and the Bissett and Bird River regions of southeastern Manitoba. Phanerozoic investigations focused on completing the surficial geology compilation for the province and the inception of a multi-agency Phanerozoic lineament study.

New field projects were initiated in

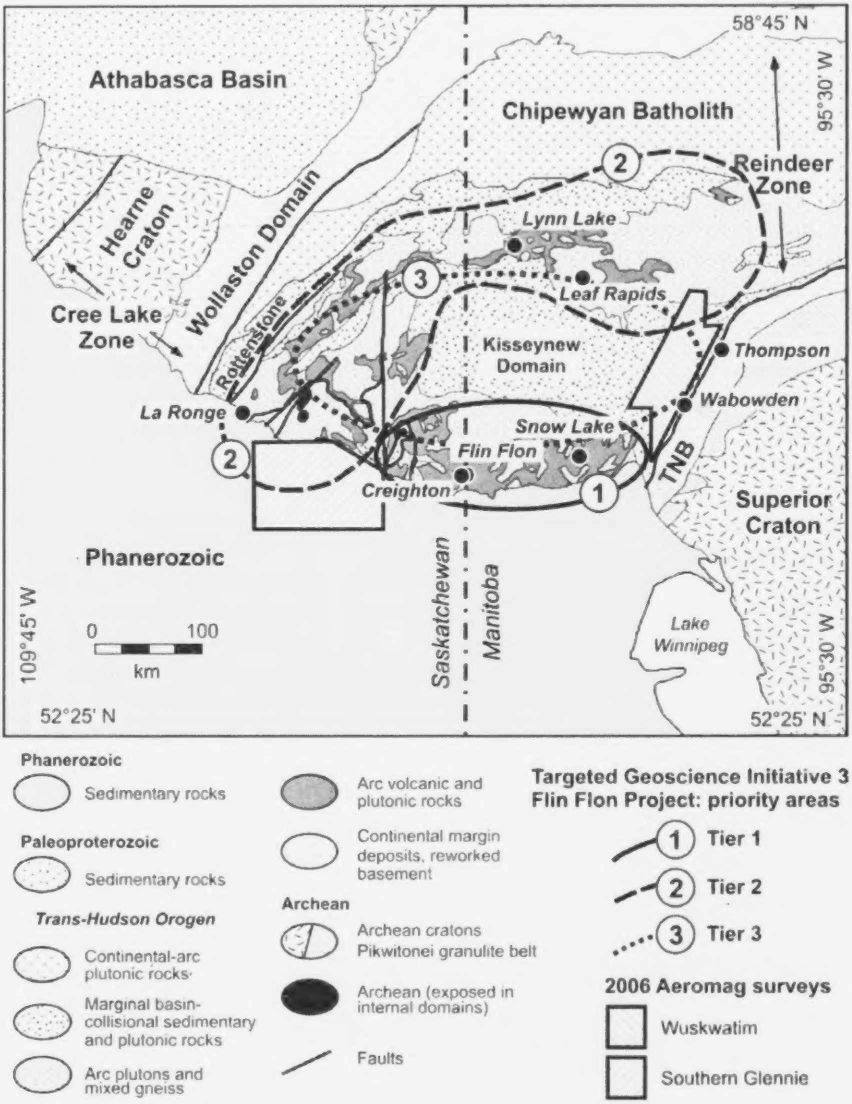
- the northern Superior Province, at Bear Lake, as the first year of a multiyear project aimed at updating the bedrock mapping database for greenstone belts in the region;
- the Kasmere Lake area of Manitoba's far north, with a multidisciplinary approach spanning bedrock mapping, isotope geochemistry, mineral-deposit investigations and Quaternary mapping and sampling; and
- the Wuskwatim Lake and Flin Flon areas, as contributions to the Targeted Geoscience Initiative.

Targeted Geoscience Initiative

In February 2005, the Government of Canada committed $25 million over five years to extend the mission of the Targeted Geoscience Initiative (TGI) Program, which has included two previous programs (TGI-1 in 2000–2003 and TGI-2 in 2003–2005). These are partnership programs delivered in collaboration with provincial geological surveys and with participation by industry and universities.

The TGI-3 Flin Flon project is an integrated, multidisciplinary geoscience study to aid in the discovery of new reserves of base metals in vulnerable, established mining communities of Manitoba and Saskatchewan (the area encompassing Flin Flon, Snow Lake, Leaf Rapids, Thompson–Wabowden (exclusive of the Thompson Nickel Belt), Lynn Lake, La Ronge and Creighton). The objective is to develop and test new geoscientific models, methods and approaches that will guide exploration in this highly prospective area of the Canadian Shield. The project has been developed through joint provincial-federal-industry consultation and will be delivered as a fully integrated tripartite partnership including the minerals industry, researchers from Laurentian and McGill universities, and geologists from MGS, the Saskatchewan Geological Survey and the Geological Survey of Canada (GSC). The project will comprise three major subcomponents (Figure 1):

1) Tier One (highest priority) subcomponent will focus on base-metal-rich portions of the Glennie–Flin Flon–Snow Lake district, and will include geoscience directly related to extending existing reserves of base metals and bringing to light new occurrences in the district; subprojects include
   - a 1:10 000 bedrock map of the immediate Flin Flon area and supporting geoscience studies, including stratigraphy, volcanic architecture and structure;
   - a camp-scale 3-D 'knowledge cube', underpinned by a 2-D seismic study and subsurface geochemical, stratigraphic and structural data incorporated from existing Hudson Bay Exploration and Development Co. Ltd. drilling;
   - supporting geoscience studies in Snow Lake;
   - airborne surveys of part Saskatchewan's southern Glennie Domain (completed 2006) and northern Hanson Lake Block, and remote predictive interpretation maps based on integration of the airborne surveys with targeted new mapping; and
   - ore mineralogy, sulphide geochemistry and isotopic studies.
2) Tier Two (second priority) subcomponent will focus on regional Trans-Hudson Orogen base-metal potential and includes
   - magmatic Ni–platinum group element (PGE) potential, lithogeochemistry and isotopic studies of selected targets in the northern and western Lynn Lake and La Ronge greenstone belts;
   - synthesis of the surficial geology of Saskatchewan and Manitoba, including supporting till geochemical analyses, airphoto interpretation and targeted surficial mapping;
   - an airborne survey in the Wuskwatim Lake area west of Thompson (completed 2006), associated targeted field mapping and supporting isotopic and geochemical analyses, resulting in new 1:100 000 maps of the eastern Kisseynew Domain; and
   - an airborne survey in the Partridge Breast Lake area, north of Leaf Rapids, and updated bedrock geological maps of the Lynn Lake–Partridge Breast Lake area.


58°45' N
95°30' W
Athabasca Basin
Chipewyan Batholith
Reindeer Zone
Hearne Craton
Wollaston Domain
Lynn Lake
Leaf Rapids
Cree Lake Zone
Rottenstone
Kisseynew Domain
Thompson
Wabowden
La Ronge
Snow Lake
Flin Flon
Creighton
TNB
Superior Craton
Phanerozoic
Saskatchewan
Manitoba
109°45' W
0
100
km
Lake Winnipeg
52°25' N
95°30' W
52°25' N
Phanerozoic
Sedimentary rocks
Paleoproterozoic
Sedimentary rocks
Trans-Hudson Orogen
Continental-arc plutonic rocks
Marginal basin-collisional sedimentary and plutonic rocks
Arc plutons and mixed gneiss
Arc volcanic and plutonic rocks
Continental margin deposits, reworked basement
Archean
Archean cratons
Pikwitonei granulite belt
Archean (exposed in internal domains)
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2 Tier 2
3 Tier 3
2006 Aeromag surveys
Wuskwatim
Southern Glennie

***Figure 1:** Targeted Geoscience Initiative areas of focus in the Flin Flon–Snow Lake–Wabowden–Thompson–Leaf Rapids–Lynn Lake–La Ronge–Creighton area of the Trans-Hudson Orogen in Manitoba and Saskatchewan.*

3) Tier Three (lowest priority) subcomponent will focus on regional definition of iron oxide–copper–gold (IOCG) potential through fieldwork and supporting lithogeochemical and isotopic studies.

Precambrian mapping

Flin Flon–Snow Lake belt

Staff from the Manitoba, Saskatchewan and Canadian geological surveys joined researchers from Laurentian University in a group of interrelated mapping projects spanning the Manitoba–Saskatchewan border as part of the Flin Flon TGI-3 project. The centerpiece of collaborative mapping activities is a new 1:10 000 scale 'cross-border' geological map of the Flin Flon area. In 2006, Renée-Luce Simard (MGS) focused on the Schist Lake–Mandy mines area, 4 km south of Flin Flon (GS-1). This new mapping allowed recognition of rocks comparable to those in the hangingwall to the Flin Flon–Callinan–Triple 7 ore deposits. Volcanogenic massive sulphide deposits in the Flin Flon area occur in association with the felsic volcanic units in synvolcanic collapse structures and calderas within the main mafic volcanic complex, so the ability to recognize these structures is crucial to exploration in and around Flin Flon.

Laurentian University researchers Harold Gibson and

Ph.D. candidate Michelle DeWolfe continued detailed mapping in the footwall and hangingwall rocks of the Flin Flon, Callinan and Triple 7 deposits (GS-2). This work is aiding in the definition of exploration targets through the development of a robust local stratigraphy, recognition of synvolcanic subsidence structures and recognition of structural repetition in the volcanic stratigraphy.

Superior Province

New work was initiated at Bear Lake in the northern Superior Province by Christian Böhm (MGS) and Russell Hartlaub (British Columbia Institute of Technology; GS-7). The Bear Lake area hosts several shear-zone-bounded panels of volcanic and sedimentary rocks at lower to middle amphibolite facies, comparable to supracrustal rocks of the Hayes River and possibly Oxford Lake groups at northern Oxford Lake and southwestern Knee Lake. Together with planned mapping in the Atik Lake area, this study will provide an improved geological context and regional framework for base and precious metal exploration in this part of the northern Superior Province.

Superior Boundary Zone and eastern Kisseynew Domain

High-resolution images from the 2006 Wuskwatim Lake aeromagnetic survey (Figure 1) were used in conjunction with new mapping by John Percival (GSC), Herman Zwanzig and Linda Murphy (MGS), and isotopic data (Nicole Rayner, GSC) to reinterpret the geology of the Kisseynew Domain west of the TNB (GS-8 and -10). The results suggest that a 60 km wide zone, previously considered to consist entirely of Paleoproterozoic Burntwood Group migmatite and granite, is structurally interleaved with heterogeneous gneiss, which resembles Superior Province basement and the lower part of its Paleoproterozoic metasedimentary cover sequence (Ospwagan Group). These units are exposed in structural culminations, suggesting they are widely distributed beneath a structural cover of the Burntwood Group in the northeastern Kisseynew Domain. Metamorphic assemblages in the Wuskwatim Lake corridor indicate upper amphibolite and granulite facies conditions in Burntwood migmatite, as well as in the structurally underlying basement-cover sequence. A major implication of this work is that Thompson-type nickel mineralization may exist within the Ospwagan-like rocks present in the 60 km wide zone west of the TNB proper.

Thompson Nickel Belt

Two samples of the Pipe Formation in the TNB were processed for U-Pb sensitive high-resolution ion microprobe (SHRIMP) ages of detrital zircons in an attempt to further constrain the age of deposition of the Ospwagan Group, which hosts the nickel deposits (Rayner, Percival [GSC] and Zwanzig [MGS]), GS-11). A pelite from the Thompson mine and semipelite from the Pipe II pit both yielded a population of exclusively Neoarchean grains with the primary age mode of ca. 2.7 Ga, similar to previous work on the entire Ospwagan Group sediment section. The simple distribution of detrital zircon ages can help to distinguish the nickel-hosting Ospwagan Group from other similar-looking rocks in northern Manitoba and thus delimit areas for nickel exploration.

Chris Couëslan (Ph.D. candidate, University of Calgary) conducted field investigations on the Hudsonian metamorphism of supracrustal rocks in the TNB (GS-12). Such studies are important because the character of Ospwagan Group metasedimentary rocks varies greatly with metamorphic grade, so documentation of their characteristics at different metamorphic grades will greatly increase the ability to recognize Ospwagan Group rocks throughout the TNB. Preliminary results suggest that grades may be higher along the eastern side and southern end of the belt and lower along the western side and northern end of the belt.

Far north

As part of the Manitoba Geological Survey's initiative to update the geological knowledge base of Manitoba's far north, field investigations in 2006 were focused on the Kasmere Lake and Putahow Lake areas (Böhm, Anderson and Matile; GS-13 and -14). Detailed bedrock mapping and sampling were undertaken for lithogeochemical, isotope geochemical and geochronological studies to improve the currently limited understanding of the nature and evolution of this portion of Manitoba's Precambrian shield, and to support ongoing uranium and gold exploration in the area. Bedrock exposures at Kasmere and Putahow lakes are divided into metasedimentary rocks of the Paleoproterozoic Wollaston Domain and younger, Paleoproterozoic granitic intrusions and pegmatite. Mineral exploration by private exploration companies and field mapping by MGS have discovered showings of uranium, gold and sulphides in the region. Landscape analysis in the Kasmere–Putahow lakes area underlines the importance of the distribution of subglacial meltwater-flow corridors when determining the bedrock source for mineral anomalies.

Mineral deposits studies

Bissett

In 2002, MGS initiated a program of bedrock mapping, structural analysis, lithogeochemistry, isotopic studies and geochronology in the Garner–Gem lakes area, 45 km southeast of Bissett. In the 2006 field season, Scott

Anderson conducted 1:20 000 scale bedrock mapping in the area in order to extend detailed mapping coverage into some poorly understood and complex areas east of the Manigotagan River and south of Gem Lake (GS-15). This work has resulted in a better understanding of the rock types, stratigraphy, structure and deformation history of the various supracrustal assemblages in the area. The geochemistry of rhyolite in one package suggests significant volcanic-hosted massive sulphide potential. This work also provides an improved context for a series of locally auriferous stockwork-breccia quartz-vein systems north of Gem Lake.

Bird River

In 2005, MGS initiated a government-industry-university partnership in the Bird River Belt of southeastern Manitoba. Partners in the initiative include MGS, researchers and graduate students at the University of Waterloo (partially funded by Gossan Resources Limited, Mustang Minerals Corp., Tantalum Mining Corporation of Canada Limited (Tanco), the university and the Natural Sciences and Engineering Research Council of Canada). The group is undertaking mapping, structural analysis and geochronological investigations in order to better understand both the evolution of the Bird River Belt and the setting of the various deposit types, and will aid in supporting the exploration programs that are currently underway in the area.

Paul Gilbert continued his regional mapping project in the Bird River Belt with detailed mapping in the eastern part of the belt, focusing on stratigraphy and volcanic geochemistry (GS-17). This work has defined back-arc-basin-type and arc-type volcanic sequences, as well as turbidites and fluvial-alluvial deposits that post-date the arc-type rocks by approximately 30 m.y.

Field investigations in 2006 by University of Waterloo postdoctoral fellow Manuel Duguet on the north flank of the Bird River Belt focused on the structural relationships between the Maskwa Batholith and the different units of the Bird River Belt (GS-16). These investigations highlighted the importance of the Peterson Creek Shear Zone in the structural framework of this part of the belt. Stratigraphic subdivisions and structural interrelationships have been revised accordingly.

Paul Kremer (Waterloo University) continued M.Sc. work to examine the structural geology of the Bernic Lake Formation and provide constraints on the emplacement of contained rare element pegmatites (GS-18). Field components of the study included geological mapping (1:10 000 scale) of the Bernic Lake Formation around the Tanco mine, detailed geological mapping of exposed pegmatite occurrences within the Bernic Lake pegmatite group, examination of both production and exploration diamond-drill core from the Tanco mine, and underground mapping of the Tanco pegmatite.

Caroline Mealin (University of Waterloo) continued M.Sc. work on the Bird River Sill, a mafic-ultramafic layered intrusion within the Bird River Belt (GS-19). The Bird River Sill is currently an exploration target for Ni-Cu-PGE deposits and hosts the past-producing Maskwa west and Dumbarton Cu-Ni deposits. Integrated detailed mapping, structural, geochemical and mineral deposit investigations have led to a new model for the emplacement of the ultramafic and mafic rocks that constitute the sill, with implications for sulphide and PGE mineralization. Several new sulphide-bearing localities have also been identified.

Snow Lake

A metallogenic and metamorphic study of selected gold-bearing deposits from Snow Lake and the southern flank of the Kisseynew Domain by McGill University Ph.D. candidate Simon Gagné (GS-4) is supported by MGS and GSC. During the 2006 field season, four gold-bearing mineral deposits, ranging from lower to upper amphibolite facies, were investigated (Chisel North, Nokomis Lake, Puffy Lake and Squall Lake). Examination of the sulphide-gold mineralization in these deposits will provide new constraints on the timing of mineralization and the possible effects of increasing pressure and temperature on the evolution of the sulphide-gold mineralization. This information will provide useful guidelines for explorationists to help in the selection of exploration targets in medium- to high-grade metamorphic terranes.

Phanerozoic investigations

Williston Basin TGI project

The 'Williston Basin Architecture and Hydrocarbon Potential' TGI project is a multidisciplinary geoscientific study aimed at characterizing and understanding basin architecture and hydrocarbon potential in the Williston Basin. This two-year study ended formally in March 2005, but work continues to complete and publish project products. Interprovincial subsurface stratigraphic correlations for the entire Phanerozoic section have been completed (Bezys, GS-23). Final map production for the project is to be completed by March 2007.

Cross-border correlations of the Bakken Formation, Three Forks Group stratigraphic interval coincided with the discovery of the Sinclair field, which is being explored for conventional oil. Co-operative maps and discussions between Manitoba and Saskatchewan have helped in the understanding of the dynamics of this new play.

The compilation of all oil and gas shows throughout the Phanerozoic section has also been a useful exploration tool for the industry, particularly in the Mesozoic, which was not compiled prior to the start of this project. The recently constructed, detailed and accurate basin-wide model of the geohydrological dynamics of the Williston Basin system will be valuable for understanding oil-water migration pathways through the Phanerozoic section (particularly the Paleozoic).

Phanerozoic lineament study

A study to compile Phanerozoic structural information for the Western Canada Sedimentary Basin was begun by Jim Bamburak, in collaboration with the Alberta and Saskatchewan geological surveys (Bezys, GS-23). The joint prototype structural database has been designed to document structures that may have localized hydrocarbon and metal-bearing fluids in traps within the Phanerozoic stratigraphic package.

Surficial geology compilation of Manitoba

In 2006, thirty-seven 1:250 000 scale surficial geology maps, four 1:500 000 scale maps, and a prototype of the 1:1 000 000 scale map were produced by Gaywood Matile and Greg Keller, completing coverage of the entire province (Bezys, GS-23). The new maps will be in digital formats that can be queried (in addition to traditional hardcopy versions) and will be an important tool for mineral exploration and land-use planning.

Stratigraphic drilling

Two stratigraphic coreholes were drilled west of Lake Winnipegosis under the 2006 Corehole Drilling Program (Bamburak, GS-24). Devonian stratigraphic studies help not only to resolve stratigraphic problems, but may also provide a further understanding of metal migration-emplacement in an area where anomalous sequences exist. Historically, anomalous lead-zinc mineralization has been found in Devonian and Silurian formations that are situated within or updip of the Superior Boundary Zone. Consequently, there is potential for Mississippi Valley–type mineralization for more than 100 km along the trend of the Superior Boundary Zone in west-central Manitoba.

Aggregate

The Rural Municipality (R.M.) of Ste. Rose was mapped this year as part of an ongoing project to update aggregate information in the province (Groom, GS-22). The R.M. of Ste. Rose has been very fortunate to have an abundance of high-quality aggregate in the beach ridges in the area. Although many of the pits in the producing beach ridge are near depletion, it still contains large reserves of aggregate.

Other projects

Igneous carbonate-rich rocks from Wekusko Lake

The petrography, mineralogy and geochemistry of two macroscopically distinct drillcore samples of 'kimberlitic' rock from the southern Wekusko Lake area were examined in detail by researchers from the University of Manitoba and MGS (Chakhmouradian, Böhm and Greville, GS-5). The two studied samples are tentatively identified as magnesiocarbonatite, likely derived from a mantle source similar to those that produce kimberlite. In common with kimberlite, carbonatitic magma can potentially transport diamonds from the mantle. Further studies of the Wekusko Lake magnesiocarbonatite and its constituent minerals by isotope-analytical techniques will be required to constrain the source and evolutionary history of these rocks.

Hydrological dynamics in the Winnipeg River basin

The Winnipeg River in northwestern Ontario provides nearly half of the total flow into Lake Winnipeg and the Nelson River, and is the most important component of the hydroelectric system that generates power for Manitoba. A continuing study by Scott St. George at the GSC (GS-20) uses a network of long-term discharge gauges to examine the frequency, severity and causes of drought in the basin during the last one hundred years. Understanding the dynamics of the Winnipeg River basin, including the causes of severe droughts and long-term trends, is critical to developing accurate estimates of future hydroelectric power production in Manitoba.

Revegetation of tailings at the Gunnar minesite

University of Manitoba researchers continued with a program investigating revegetation of mine tailings. A preliminary field experiment was designed to test the effects of tilling, fertilizing and amending Gunnar tailings with paper-mill sludge on plant establishment and growth (Renault, GS-21). Research oriented towards using readily available amendments, such as paper-mill sludge, to increase revegetation success on such sites would benefit the paper-mill industry and the mining industry, as well as the government and future land users.

Regional offices

The Flin Flon office continued to provide technical and regulatory assistance to the mining and mineral-exploration communities in northwestern Manitoba. These activities included recording new mineral claims and accepting applications and submissions required under *The Mines and Minerals Act*, answering claim-status and other *Act*-related inquiries, and maintaining a collection of current claim and land-status maps for the

Province of Manitoba (Heine, GS-6). The office staff includes the Regional Geologist (Tom Heine), Resident Geologist (David Prouse), Deputy Mining Recorder (Tana White) and Claims Inspector (Dale Wride).

Core storage facilities

The Mineral Resources Division considers the archiving of exploration drillcore to be a valuable data source for use by mineral-exploration companies and researchers. Drillcore storage facilities are located in Winnipeg (Midland and Brady Road), The Pas, Flin Flon, Thompson and Lynn Lake (Prouse, GS-25). Clients can access drillcore for viewing and study at these locations. Six of the core libraries have lighted, heated inspection rooms with benches, and most have core splitters. It is estimated that the Manitoba Geological Survey's Precambrian drillcore libraries currently contain more than 260 000 m of core.

Compilation and partnerships

The Manitoba Geological Survey is engaged in 34 partnered initiatives, including contributions from the federal government, the mineral industry and several Canadian universities. Partnerships added approximately $1.4 million to geoscience programming in Manitoba for 2006–2007, and represent significant leverage of the MGS geoscience budget. The projects facilitate the training of future geoscience professionals, including in 2006 two postdoctoral fellows, four Ph.D. candidates, five M.Sc. candidates and three Honours B.Sc. students. Primary focuses for partnerships in 2006 were the Flin Flon TGI project and the Bird River suite of projects.

Geoscience Information Services

In 2006, the Geoscience Information Services section devoted considerable time to a number of major projects and many smaller projects in support of the Geological Survey's research activities. Major projects included the following:

- Williston Basin Hydrocarbon Potential project (TGI-2): More than 200 isopach and structure contour maps have been produced using a standardized database combining Manitoba and Saskatchewan data.
- Manitoba Geochronology Database: This database was rereleased in November 2005 after verification of all data currently entered and standardization of geological and bibliographic information.
- Bedrock Geology Compilation Map program: Recompilation and updating of existing maps to produce a seamless 1:250 000 scale digital geological base for Manitoba has been completed for approximately half the province.
- Compilation of the Thompson Nickel Belt based on the work of J. Macek and H. Zwanzig: More than a million hectares of the TNB have been compiled into a seamless geodatabase that includes an upgraded topographic base incorporating detailed infrastructure, geology and several thousand structural measurements. These data are being released as an Open File digital dataset, to be followed in 2007 by individual final maps.

Mineral Deposits Database

The Mineral Deposits Database currently used to support the Map Gallery presentation is being redesigned as an Oracle database (Heine, GS-26). A considerable mineral deposit-occurrence archive is currently compiled in the Mineral Inventory Cards and Mineral Deposit Report series (both via the Internet; the latter accessible through the Map Gallery). The newly designed database will centralize all mineral deposit data currently available and provide users with a search engine to customize queries. The database design is complete and porting of data from the old system to the new database is underway. Version 1 of the database should be ready for release (on CD-ROM) by November 2007.

Client services and outreach

In 2005–2006, MGS published seven geoscientific reports, including the annual *Report of Activities*, and 38 maps. In response to client needs, the majority of the publications were released in hard copy for purchase through Publication Sales and in electronic format for free download via the Web.

Manitoba Geological Survey mineral-education outreach initiatives included the Manitoba Mining and Minerals Convention Schools Program, National Engineering and Geoscience Week, and Provincial Mining Week. The latter offered free, hands-on activities developed to complement the earth sciences curriculum and help increase public awareness of Manitoba's mineral resources and mining industry. The event drew more than 4000 visitors from the general public and the school tours program.

A number of MGS staff, including Vanessa James, Ruth Bezys, Elaine Stevenson and Peter Leskiw, contributed to the development and delivery of the Prospector Training Program module, entitled 'Business of Prospecting'. Eleven students who had already graduated from the Wilderness Safety and Prospector Training modules attended the Business of Prospecting program held in November of 2005. Course topics included raising venture capital; listing, describing and selling a property; marketing; joint ventures; and information sources and research.

Elaine Stevenson, the MGS outreach programs co-ordinator, also organized the 2nd annual Aboriginal

Mining Workshop, which was held as part of the November 2005 Manitoba Mining and Minerals Convention and drew 48 participants. The workshop focused on how communities can benefit from mineral exploration activity in their regions.

Survey staff delivered mining and geology presentations to Aboriginal communities and schools in Cross Lake, Oxford House and Hollow Water, as well as at the Assembly of Manitoba Chiefs Youth Gathering and St. John's Ravenscourt. In addition, staff attended Aboriginal conferences, such as Vision Quest, the Northern Association of Community Councils and the Canadian Aboriginal Minerals Association.

An article on mineral exploration in northern Manitoba was published in the Community Contact newsletter distributed by Manitoba Aboriginal and Northern Affairs. The article describes the mining cycle, potential job and business opportunities, the location of exploration projects and how communities and individuals can learn more and participate.

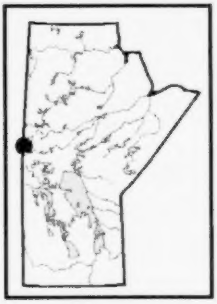
Acknowledgments

The careful work of MGS geologists, lab technicians, expeditors, students, cartographers, publication staff and administration went into the production of the Report of Activities 2006. Bob Davie, Joan Dawson and Nicole Robinson of RnD Technical carefully performed technical editing and Craig Steffano completed the final layout for publication.

GS-1

Geology of the Schist Lake–Mandy mines area, Flin Flon, Manitoba (part of NTS 63K12)

by R-L. Simard



Simard, R-L. 2006: Geology of the Schist Lake–Mandy mines area, Flin Flon, Manitoba (part of NTS 63K12); *in* Report of Activities 2006, Manitoba Science Technology, Energy and Mines, Manitoba Geological Survey, p. 9–21.

Summary

The Flin Flon area of the Paleoproterozoic Flin Flon Belt is well known for its volcanogenic massive sulphide (VMS) deposits. With the intent of assisting industry in the search for new reserves/mines in established mining communities, the Government of Canada launched in 2005 a new five-year Targeted Geoscience Initiative (TGI-3) in the Flin Flon area. As part of this initiative, the Manitoba Geological Survey, in collaboration with other surveys and researchers, is participating in the production of a new 1:10 000 scale 'cross-border' geological map of the Flin Flon area. This report summarizes the findings of the first field season for this project.

The Schist Lake–Mandy mines area, 4 km south of Flin Flon, was the focus of 1:5000 scale geological mapping during the 2006 field season. This new mapping allowed recognition of rocks comparable to those in the hangingwall to the Flin Flon–Callinan–Triple 7 ore deposits (i.e., the Hidden and Louis formations) as far south as Green Lake. The area is dominated by these rocks, which form the core of the mapped area and are bounded by the Burley Lake Fault to the west and the Mandy Road Fault to the east. The new mapping identified a potential VMS-hosting environment in the Hidden formation just southeast of Carlisle Lake. This area is considered to be of potential economic interest as it contains a subsidence structure with synvolcanic faults, a previously unrecognized felsic extrusive dome, and areas with pronounced gossan development on the rocks.

Introduction

The Flin Flon area of the Paleoproterozoic Flin Flon Belt is well known for its volcanogenic massive sulphide (VMS) deposits. Three active (Callinan, Triple 7 and Trout Lake) and three past-producing (Flin Flon, Mandy and Schist Lake) VMS mines occur in the immediate vicinity of the town of Flin Flon, which makes this area one of the most productive base-metal regions in Canada. Despite its productive past, however, Flin Flon area's reserves are rapidly being depleted and new reserves/deposits are needed to maintain the economic viability of the Hudson Bay Mining and Smelting Co. Ltd. smelter at Flin Flon.

With the intent of stimulating private-sector resource exploration in areas of high base-metal potential in established mining communities, the Government of Canada launched a new five-year Targeted Geoscience Initiative (TGI-3) in 2005. As part of this initiative, the Manitoba Geological Survey, in collaboration with the Saskatchewan Geological Survey, the Geological Survey of Canada, and researchers from Laurentian University, is participating in production of a new 1:10 000 scale 'cross-border' geological map of the Flin Flon area.

This report summarizes the first year of observations and data collected during a nine-week field program of 1:5000 scale bedrock geological mapping in the Schist Lake–Mandy mines area, located 4 km south of Flin Flon. The field and analytical studies in this area are intended to characterize and differentiate the various volcanic sequences, provide constraints on their distribution and assess their stratigraphic position relative to those hosting the VMS deposits at Flin Flon.

Regional setting

The Paleoproterozoic Flin Flon Belt is part of the Reindeer Zone of the Trans-Hudson Orogen (Figure GS-1-1). The Flin Flon Belt consists of a series of tectonostratigraphic assemblages (juvenile arc, juvenile ocean-floor back arc, ocean plateau, ocean-island basalt and evolved plutonic arc) that range in age from 1.92 to 1.87 Ga. All of the VMS deposits mined to date in the Flin Flon area are associated with the juvenile Flin Flon arc assemblage (Syme et al., 1999).

The volcanic rocks of the Flin Flon area are part of the 1.9 Ga juvenile Flin Flon arc assemblage, which consists mainly of tholeiitic subaqueous pillowed basalt and basaltic andesite, with lesser amounts of heterolithic mafic breccia and mafic and felsic volcaniclastic rocks, and minor dacite to rhyolite flows (Bailes and Syme, 1989). The VMS deposits in the area occur in association with the felsic volcanic units in synvolcanic collapse structures and calderas, within the main mafic volcanic complex (Bailes and Syme, 1989; Syme and Bailes, 1993; Figure GS-1-2).

Bedrock geology of the Schist Lake–Mandy mines area

The simplified bedrock geology of the Schist Lake–Mandy mines area, based on the 2006 field season mapping at 1:5000 scale (Simard, 2006), is summarized in Figure GS-1-3. Exposure in the Schist Lake–Mandy mines area, similar to that in most of the Flin Flon area, is exceptional, with commonly 30 to 70% lichen-free outcrop. Regional

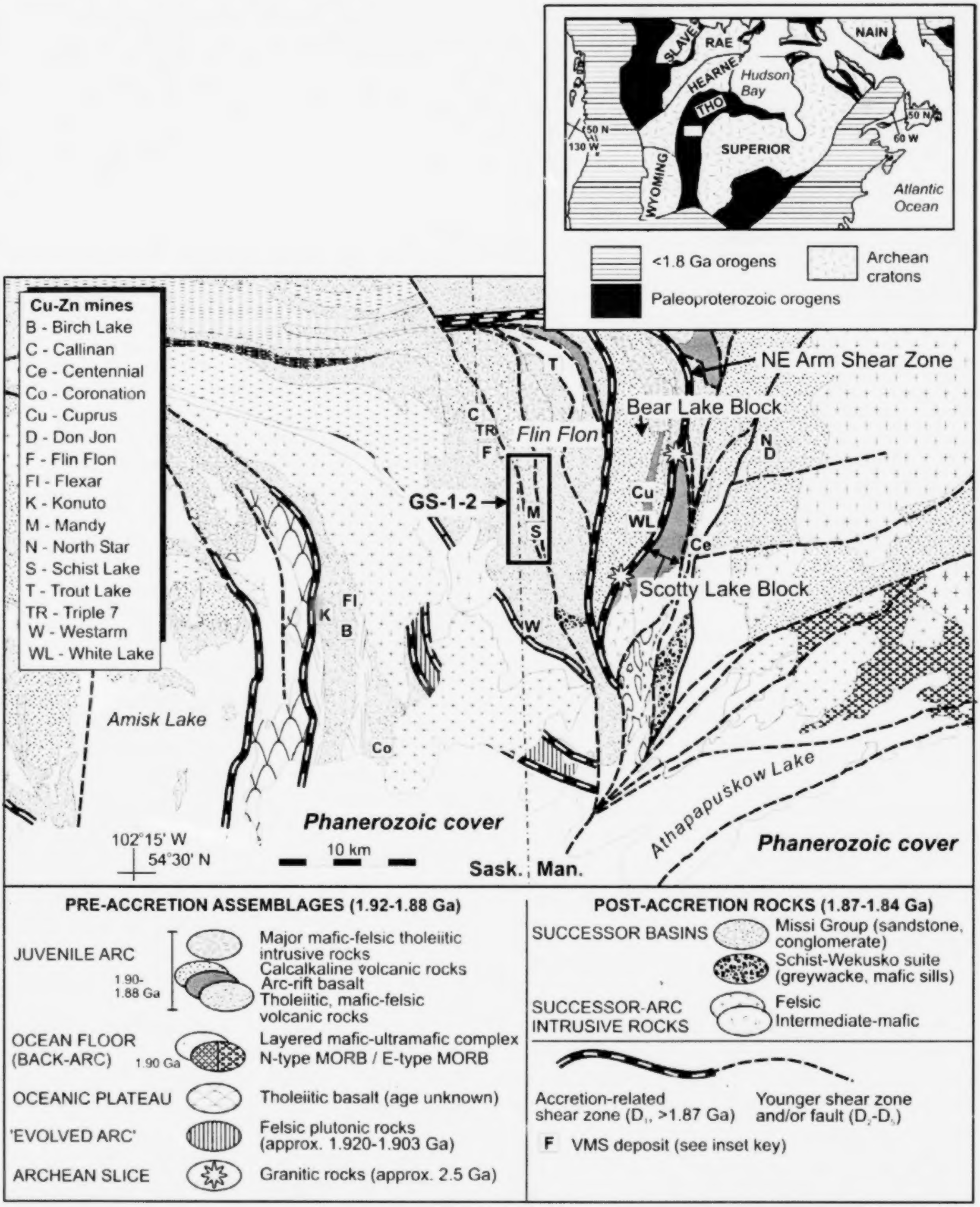

SLAVE
RAE
NAIN
HEARNE
Hudson Bay
THO
50 N
130 W
SUPERIOR
WYOMING
50 N
60 W
Atlantic Ocean
<1.8 Ga orogens
Archean cratons
Paleoproterozoic orogens
Cu-Zn mines
B - Birch Lake
C - Callinan
Ce - Centennial
Co - Coronation
Cu - Cuprus
D - Don Jon
F - Flin Flon
Fl - Flexar
K - Konuto
M - Mandy
N - North Star
S - Schist Lake
T - Trout Lake
TR - Triple 7
W - Westarm
WL - White Lake
NE Arm Shear Zone
Bear Lake Block
Flin Flon
GS-1-2
Scotty Lake Block
Amisk Lake
Athapapuskow Lake
Phanerozoic cover
Phanerozoic cover
102°15' W
54°30' N
10 km
Sask.
Man.
PRE-ACCRETION ASSEMBLAGES (1.92-1.88 Ga)
JUVENILE ARC
1.90-1.88 Ga
Major mafic-felsic tholeiitic intrusive rocks
Calcalkaline volcanic rocks
Arc-rift basalt
Tholeiitic, mafic-felsic volcanic rocks
OCEAN FLOOR (BACK-ARC)
1.90 Ga
Layered mafic-ultramafic complex
N-type MORB / E-type MORB
OCEANIC PLATEAU
Tholeiitic basalt (age unknown)
'EVOLVED ARC'
Felsic plutonic rocks (approx. 1.920-1.903 Ga)
ARCHEAN SLICE
Granitic rocks (approx. 2.5 Ga)
POST-ACCRETION ROCKS (1.87-1.84 Ga)
SUCCESSOR BASINS
Missi Group (sandstone, conglomerate)
Schist-Wekusko suite (greywacke, mafic sills)
SUCCESSOR-ARC INTRUSIVE ROCKS
Felsic
Intermediate-mafic
Accretion-related shear zone (D1, >1.87 Ga)
Younger shear zone and/or fault (D2-D5)
F VMS deposit (see inset key)

Figure GS-1-1: *Geology of the Flin Flon Belt, showing locations of known volcanogenic massive sulphide (VMS) deposits (modified from Syme et al., 1999); box indicates the area covered by Figure GS-1-2; inset map shows the location of the Flin Flon Belt within the Trans-Hudson Orogen (THO).*

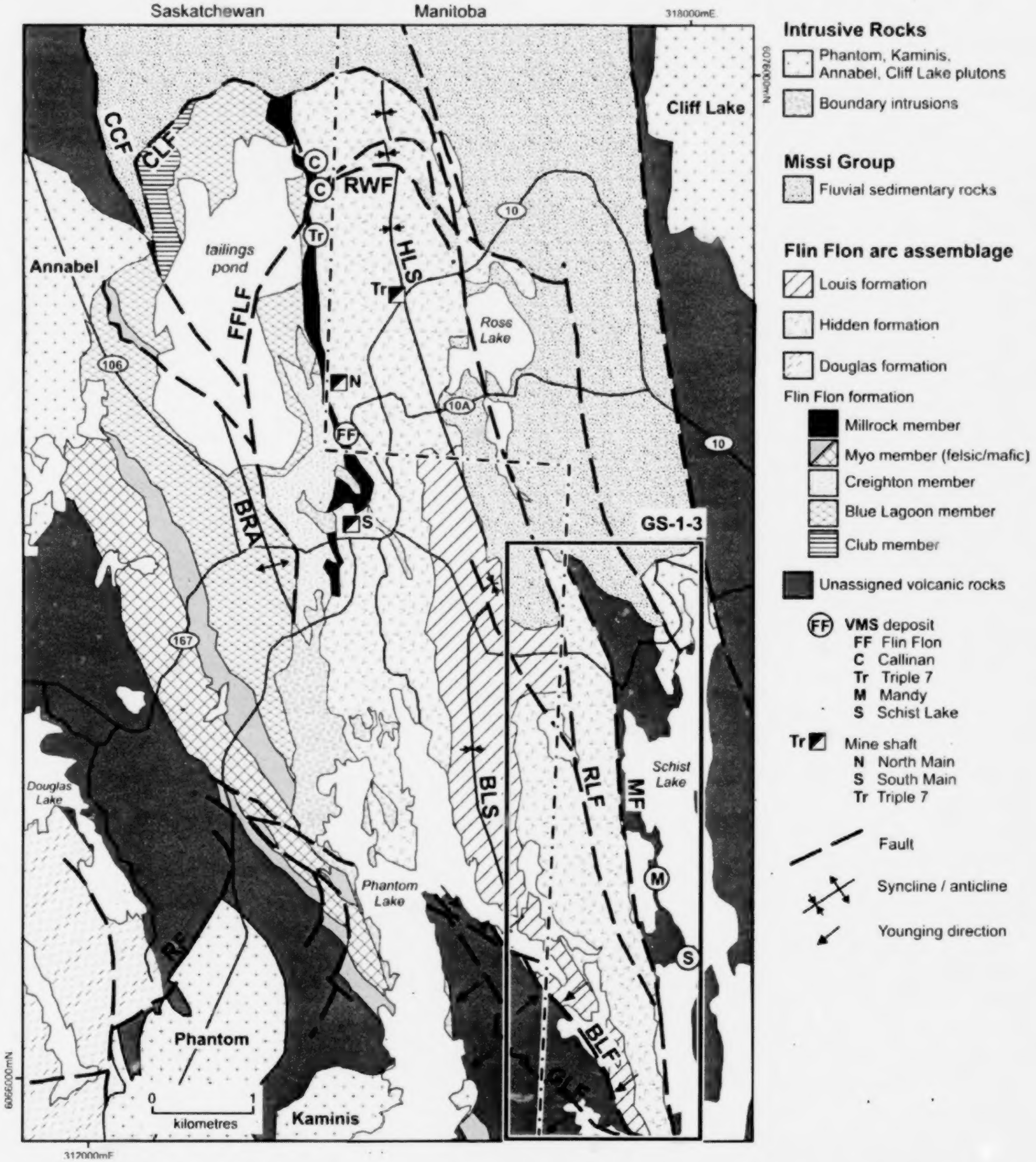

Saskatchewan
Manitoba
318000mE
6074000mN
Cliff Lake
CCF
CLF
RWF
HLS
FFLF
BRA
BLS
RLF
MF
BLF
GLF
RF
Annabel
tailings pond
Ross Lake
Schist Lake
Douglas Lake
Phantom Lake
Phantom
Kaminis
GS-1-3
10
10A
106
167
C
Tr
N
FF
S
M
0
1
kilometres
6066000mN
312000mE
Intrusive Rocks
Phantom, Kaminis, Annabel, Cliff Lake plutons
Boundary intrusions
Missi Group
Fluvial sedimentary rocks
Flin Flon arc assemblage
Louis formation
Hidden formation
Douglas formation
Flin Flon formation
Millrock member
Myo member (felsic/mafic)
Creighton member
Blue Lagoon member
Club member
Unassigned volcanic rocks
VMS deposit
FF Flin Flon
C Callinan
Tr Triple 7
M Mandy
S Schist Lake
Mine shaft
N North Main
S South Main
Tr Triple 7
Fault
Syncline / anticline
Younging direction

Figure GS-1-2: *Simplified geology of the Flin Flon area, showing the major structures in the area; box indicates the area covered by Figure GS-1-3. Abbreviations: BLF, Burley Lake Fault; BLS, Burley Lake syncline; BRA, Beaver Road anticline; CCF, Creighton Creek Fault; CLF, Cliff Lake Fault; FFLF, Flin Flon Lake Fault; GLF, Green Lake Fault; HLS, Hidden Lake syncline; MF, Mandy Road Fault; RF, Rio Fault; RLF, Ross Lake Fault; RWF, Railway Fault.*

metamorphism is lower greenschist facies (epidote-chlorite; Bailes and Syme, 1989), with good preservation of primary textures. The rocks in the area are weakly deformed, with one to two faint foliations best observed at unit contacts or in finer grained clastic rocks. Regional and local, narrow, brittle to ductile faults commonly offset the stratigraphy. Although several shear zones, each 1 to 3 cm wide, can be observed on outcrops, the significant faults offsetting the stratigraphy are rarely exposed, commonly being located in small gullies between outcrops that form weak to strong lineaments visible on airphotos. The amount and quality of exposures in the

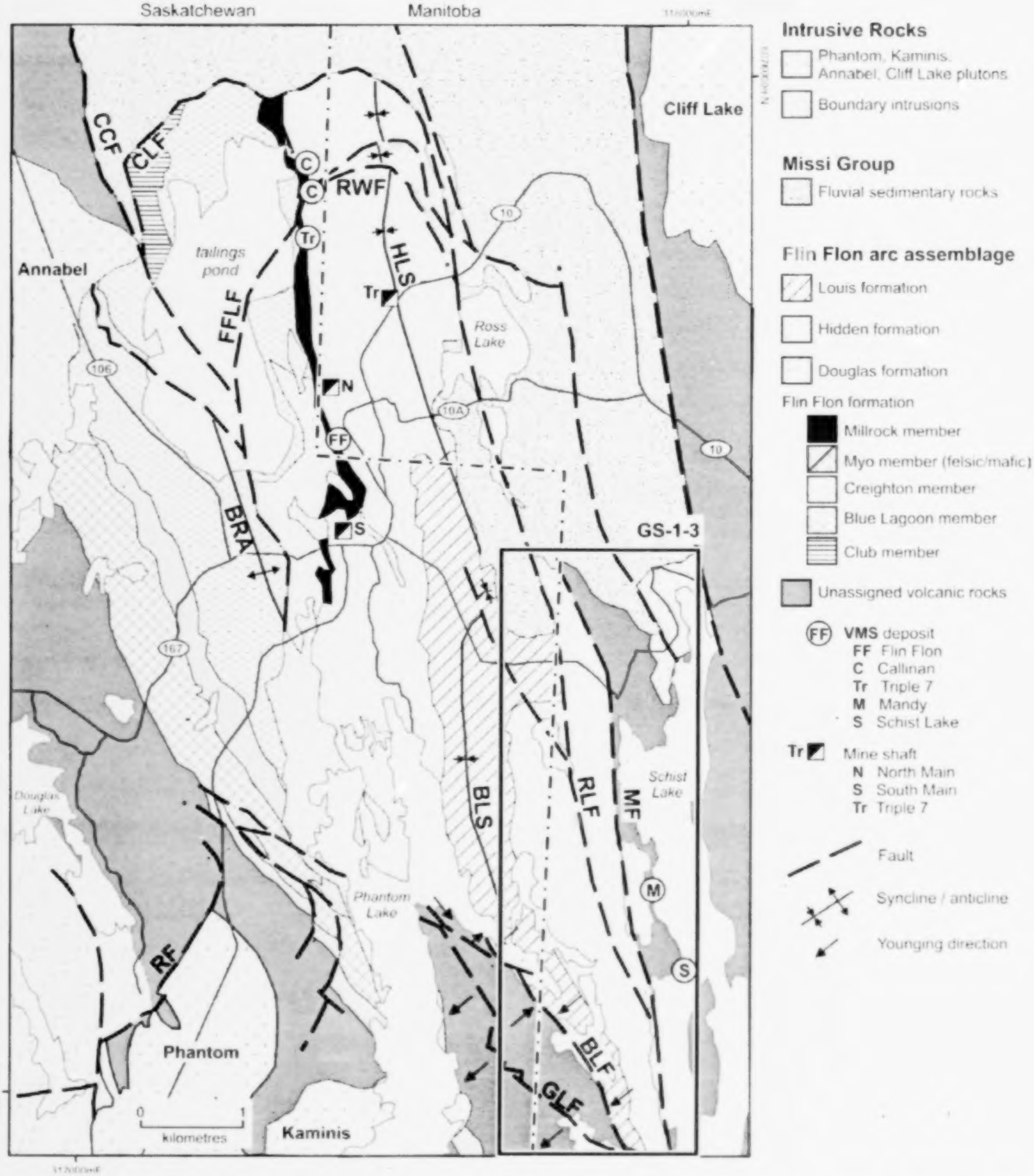

Saskatchewan
Manitoba
Intrusive Rocks
Phantom, Kaminis, Annabel, Cliff Lake plutons
Boundary intrusions
Missi Group
Fluvial sedimentary rocks
Flin Flon arc assemblage
Louis formation
Hidden formation
Douglas formation
Flin Flon formation
Millrock member
Myo member (felsic/mafic)
Creighton member
Blue Lagoon member
Club member
Unassigned volcanic rocks
VMS deposit
FF Flin Flon
C Callinan
Tr Triple 7
M Mandy
S Schist Lake
Mine shaft
N North Main
S South Main
Tr Triple 7
Fault
Syncline / anticline
Younging direction
Cliff Lake
Annabel
CCF
CLF
RWF
HLS
FFLF
BRA
BLS
RLF
MF
RF
BLF
GLF
GS-1-3
tailings pond
Ross Lake
Schist Lake
Douglas Lake
Phantom Lake
Phantom
Kaminis
kilometres
0
1
106
10
10A
167

Figure GS-1-2: Simplified geology of the Flin Flon area, showing the major structures in the area; box indicates the area covered by Figure GS-1-3. Abbreviations: BLF, Burley Lake Fault; BLS, Burley Lake syncline; BRA, Beaver Road anticline; CCF, Creighton Creek Fault; CLF, Cliff Lake Fault; FFLF, Flin Flon Lake Fault; GLF, Green Lake Fault; HLS, Hidden Lake syncline; MF, Mandy Road Fault; RF, Rio Fault; RLF, Ross Lake Fault; RWF, Railway Fault.

metamorphism is lower greenschist facies (epidote-chlorite; Bailes and Syme, 1989), with good preservation of primary textures. The rocks in the area are weakly deformed, with one to two faint foliations best observed at unit contacts or in finer grained clastic rocks. Regional and local, narrow, brittle to ductile faults commonly offset the stratigraphy. Although several shear zones, each 1 to 3 cm wide, can be observed on outcrops, the significant faults offsetting the stratigraphy are rarely exposed, commonly being located in small gullies between outcrops that form weak to strong lineaments visible on airphotos. The amount and quality of exposures in the

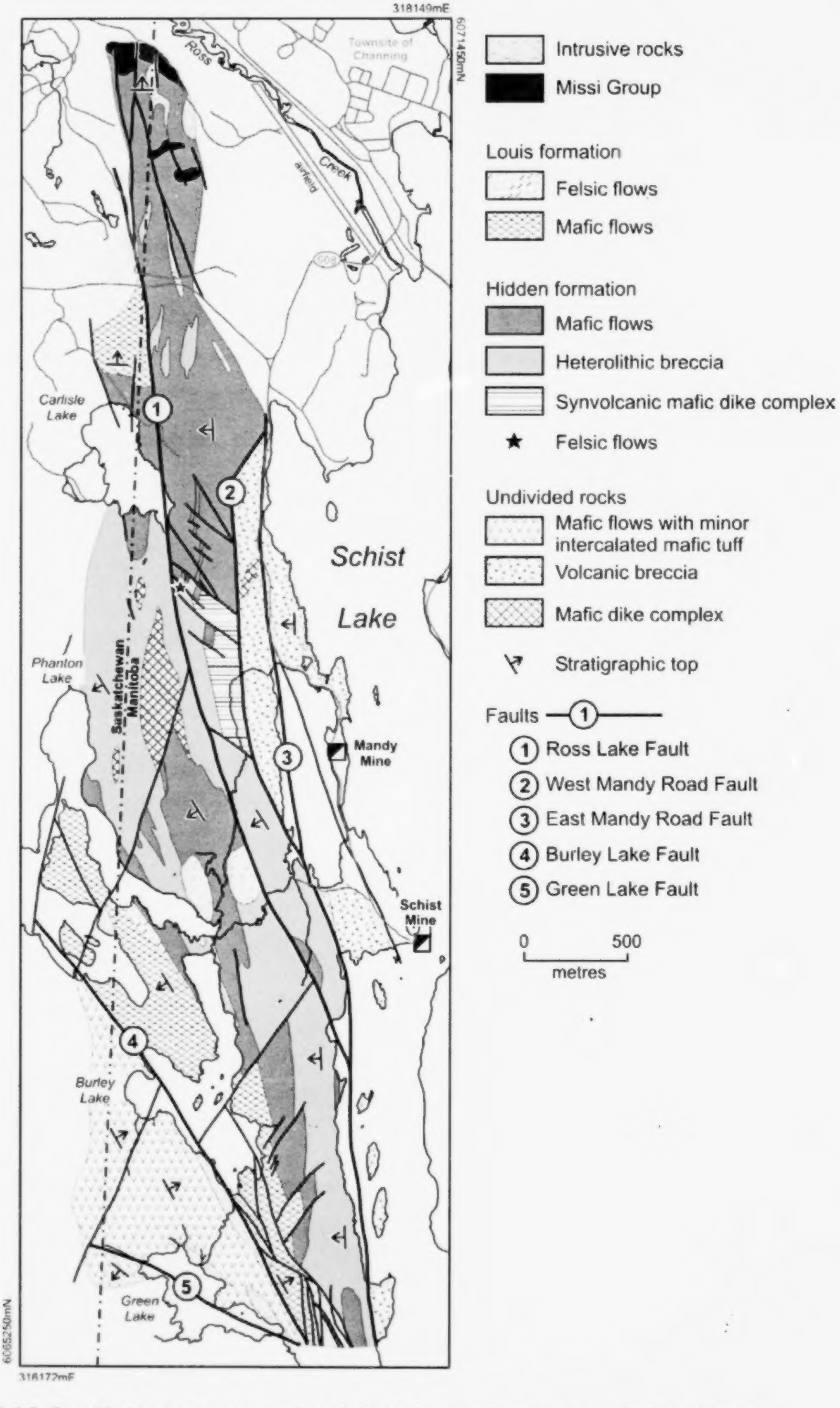

318149mE
6071450mN
Townsite of Channing
Ross
Creek
airfield
608
Carlisle Lake
1
2
Schist
Lake
Phanton Lake
Saskatchewan
Manitoba
3
Mandy Mine
Schist Mine
4
Burley Lake
5
Green Lake
6065250mN
316172mE
Intrusive rocks
Missi Group
Louis formation
Felsic flows
Mafic flows
Hidden formation
Mafic flows
Heterolithic breccia
Synvolcanic mafic dike complex
★ Felsic flows
Undivided rocks
Mafic flows with minor intercalated mafic tuff
Volcanic breccia
Mafic dike complex
Stratigraphic top
Faults
① Ross Lake Fault
② West Mandy Road Fault
③ East Mandy Road Fault
④ Burley Lake Fault
⑤ Green Lake Fault
0
500
metres

Figure GS-1-3: *Simplified bedrock geology of the Schist Lake–Mandy mines area, Flin Flon, Manitoba.*

Schist Lake–Mandy mines area allow for detailed volcanic lithofacies mapping and stratigraphic analysis of these rocks.

Recent detailed geological mapping and stratigraphic analysis of volcanic rocks of the Flin Flon mines area (Devine, 2003; Tardif, 2003; DeWolfe and Gibson, GS-2, this volume; Gibson, unpublished data, 2000–2006), have allowed the establishment of an informal stratigraphic subdivision of rocks hosting and occurring within the footwall and hangingwall to the Flin Flon, Callinan, and Triple 7 massive sulphide deposits (Figure GS-1-4a; Devine, 2003; DeWolfe and Gibson, GS-2, this volume). Figure GS-1-4 summarizes this informal stratigraphy for the Flin Flon mines area.

Rocks equivalent to the Flin Flon–Callinan–Triple 7 hangingwall strata have been recognized in the Schist Lake–Mandy mines area (Figures GS-1-2, -3, -4b). They occur west of the Mandy Road Fault, around Carlisle Lake, and east of the Burley Lake Fault (*see* Hidden Lake formation and Louis formation descriptions below). More work is required before rocks east of the Mandy Road Fault and west of the Burley Lake Fault can be associated with any of the known stratigraphic units in the Flin Flon area (*see* descriptions below).

Hidden formation

In the Schist Lake–Mandy mines area, rocks of the Hidden formation occur west of the Mandy Road Fault around Carlisle Lake (Figure GS-1-3). To the west, they are conformably overlain by rocks of the Louis formation; to the north, east of Ross Lake Fault, they are unconformably overlain by siliciclastic rocks of the Missi Group. This suite of rocks was previously mapped as andesite, basalt and flow breccia (unit 1), andesite breccia (unit 3) and porphyritic andesite breccia (unit 4) by Stockwell (1960), and as pillow fragment breccia (unit 11) and aphyric and sparsely porphyritic flows (unit 3b) and pillow fragment breccia (unit 3c) of the Burley Lake basaltic andesite (unit 3) by Bailes and Syme (1989).

The Hidden formation rocks in the Schist Lake–Mandy mines area consist of aphyric to sparsely plagioclase-phyric basalt flows with minor mafic volcaniclastic rocks to the north, and abundant heterolithic mafic breccia intercalated with aphyric to sparsely plagioclase-phyric basaltic flows to the south. They form a thick, semicontinuous, subvertical to steeply dipping volcanic sequence that trends north and faces west. The middle of this package of rocks is cut by the north-trending, sinistral, strike-slip Ross Lake Fault. The base of the Hidden

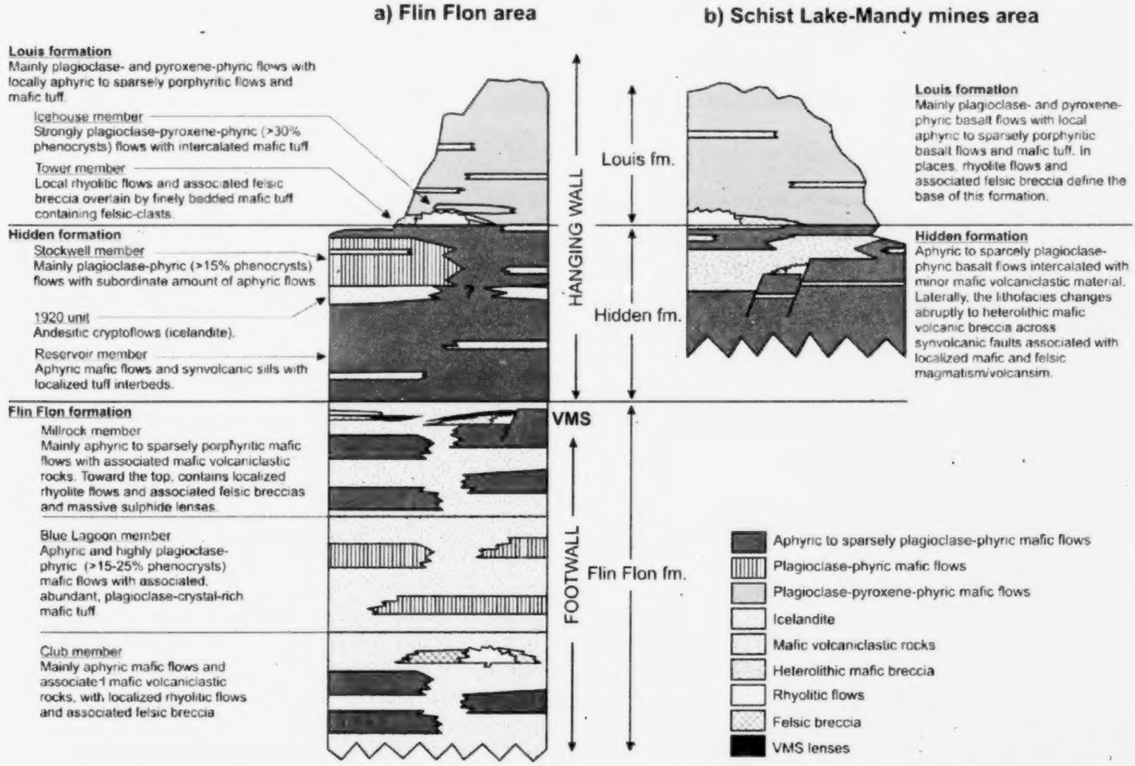

a) Flin Flon area
b) Schist Lake-Mandy mines area
Louis formation
Mainly plagioclase- and pyroxene-phyric flows with locally aphyric to sparsely porphyritic flows and mafic tuff.
Icehouse member
Strongly plagioclase-pyroxene-phyric (>30% phenocrysts) flows with intercalated mafic tuff
Tower member
Local rhyolitic flows and associated felsic breccia overlain by finely bedded mafic tuff containing felsic-clasts.
Hidden formation
Stockwell member
Mainly plagioclase-phyric (>15% phenocrysts) flows with subordinate amount of aphyric flows
?
1920 unit
Andesitic cryptoflows (icelandite).
Reservoir member
Aphyric mafic flows and synvolcanic sills with localized tuff interbeds.
Flin Flon formation
Millrock member
Mainly aphyric to sparsely porphyritic mafic flows with associated mafic volcaniclastic rocks. Toward the top. contains localized rhyolite flows and associated felsic breccias and massive sulphide lensas.
Blue Lagoon member
Aphyric and highly plagioclase-phyric (>15-25% phenocrysts) mafic flows with associated, abundant, plagioclase-crystal-rich mafic tuff.
Club member
Mainly aphyric mafic flows and associate1 mafic volcaniclastic rocks, with localized rhyolitic flows and associated felsic breccia
HANGING WALL
VMS
FOOTWALL
Louis fm.
Hidden fm.
Flin Flon fm.
Louis formation
Mainly plagioclase- and pyroxene-phyric basalt flows with local aphyric to sparsely porphyritic basalt flows and mafic tuff. In places. rhyolite flows and associated felsic breccia define the base of this formation.
Hidden formation
Aphyric to sparcely plagioclase-phyric basalt flows intercalated with minor mafic volcaniclastic material. Laterally, the lithofacies changes abruptly to heterolithic mafic volcanic breccia across synvolcanic faults associated with localized mafic and felsic magmatism/volcansim.
Aphyric to sparsely plagioclase-phyric mafic flows
Plagioclase-phyric mafic flows
Plagioclase-pyroxene-phyric mafic flows
Icelandite
Mafic volcaniclastic rocks
Heterolithic mafic breccia
Rhyolitic flows
Felsic breccia
VMS lenses

Figure GS-1-4: *Schematic stratigraphic section of the Flin Flon area:* ***a)*** *Flin Flon area schematic stratigraphy (modified from Devine, 2003; DeWolfe and Gibson, GS-2, this volume),* ***b)*** *Schist Lake–Mandy mines area schematic stratigraphy.*

formation is truncated to the east by the Mandy Road Fault. The maximum thickness of the Hidden formation in the Schist Lake–Mandy mines area is <450 m on the east side of the Ross Lake Fault and up to 800 m on the west side (Figure GS-1-3).

Aphyric to sparsely plagioclase-phyric basaltic flows

Hidden formation basalt flows in the Schist Lake–Mandy mines area usually weather buff brown to brown, but are dark green where more deformed. They are dark green on fresh surfaces. The flows are generally aphyric to sparsely plagioclase phyric, with <7% plagioclase phenocrysts (<2 mm). Flow thicknesses, which generally decrease up-section, vary significantly from >50 m for pillowed flows with minor amoeboid pillow breccia lenses near the base of the section, to 3 to 10 m for 'organized' flows (massive to pillowed to amoeboid pillowed top; massive to amoeboid pillowed top; pillowed to amoeboid pillowed top; Bailes and Syme, 1989) toward the top. The organized flows are locally intercalated with massive to well-bedded pillow breccia, heterolithic mafic breccia and mafic tuff or both (*see* description below). The basaltic flows of the Hidden formation total ~400 m east of the Ross Lake Fault by Carlisle Lake, and <250 m intercalated with important amounts of heterolithic breccia west of the Ross Lake Fault.

Pillowed flows

The thick pillowed flows generally show closely packed, well-shaped pillows, 30 to 90 cm in size, with dark reddish brown to dark green, chloritized, 1 to 2 cm thick chilled margins (Figure GS-1-5a); locally, megapillows up to 3 m in size were observed. Pillows are usually amygdaloidal (5–15% of 1–2 mm quartz-filled amygdules) and commonly show concentric thermal contraction cracks (Figure GS-1-5a). Large pillows locally show radial pipe amygdules at their margins. Interpillow material usually forms <10% of the outcrops and consists of brownish fine-grained material with angular reddish brown fragments of chilled pillow margin (hyaloclastite), or massive to well-bedded greenish mafic tuff. Where megapillows were observed, amoeboid pillow breccia formed some of the interpillow material.

Organized flows

The thinner 'organized' flows form sequences that are dominated by 5 to 10 m thick zoned flows composed of massive to megapillowed to pillowed to amoeboid pillow-breccia morphologies, and include flows both with and without the pillowed section or massive base. Where present, the massive base is usually slightly more plagioclase phyric than other parts of the flow (up to 10% plagioclase phenocrysts 1–2 mm in size), and it shows an increase in the amount and size of the quartz-filled amygdules from <2% (2 mm in size) near the base to >5% (up to 3 cm in size) close to the top. Gas cavities up to 7 cm long and 1 cm thick, partly filled with quartz, are locally observed toward the top of massive divisions. Elongated to rounded, epidote-quartz alteration patches are also commonly observed in massive flows, and increase in size and abundance toward the top of the flows (Figure GS-1-5b). The massive part of the organized flows is usually 1 to 5 m thick and grades either into megapillows and pillows with abundant smaller amoeboid pillows and amoeboid pillow breccia, or directly into amoeboid pillows and amoeboid pillow breccia (Figure GS-1-5c).

The pillowed part of the organized flows can be 0.3 to 5 m thick. Pillows are usually irregularly shaped (amoeboid) and loosely packed with abundant interpillow material, including amoeboid pillow breccia. The pillows are 0.2 to 3 m in size. They are commonly highly amygdaloidal (up to 30% of 1–5 mm quartz-filled amygdules) and show thin (<1 cm), dark reddish brown to dark green chilled margins and local epidote-quartz alteration patches. Pillowed parts of the flows typically grade both vertically and laterally into amoeboid pillow breccia.

Amoeboid pillow breccia is composed of poorly sorted, subangular, highly vesicular to scoriaceous fragments of amoeboid pillows (Figure GS-1-5d). Thin (<1 cm), dark brown to dark green chilled margins are observed on the sides of some fragments. The matrix is composed of smaller broken pieces of the same material, as well as abundant angular fragments of the chilled pillow margins, plagioclase crystals and fine mafic material.

Mafic volcaniclastic rocks

Mafic volcaniclastic rocks of the Hidden formation in the Schist Lake–Mandy mines area consist mainly of massive to crudely bedded, heterolithic, mafic volcanic breccia with lesser amounts of well-bedded, fine-grained mafic tuff. Heterolithic breccia is the dominant rock type west of the Ross Lake Fault, where it constitutes >60% of the rocks of the Hidden formation and is interbedded to the south with organized flows. It totals more than 500 m in thickness. East of the Ross Lake Fault, the heterolithic breccia is virtually absent in the north, but is the prominent unit to the south. This transition from mainly flows in the north to mainly breccia in the south is abrupt and corresponds to an important mafic and felsic dike complex along a northwest-trending fault just southeast of Carlisle Lake (*see* details below). The total thickness of breccia south of this fault structure is up to 250 m.

Heterolithic mafic volcanic breccia

Heterolithic mafic volcanic breccia of the Hidden formation usually weathers buff brown to brown and is

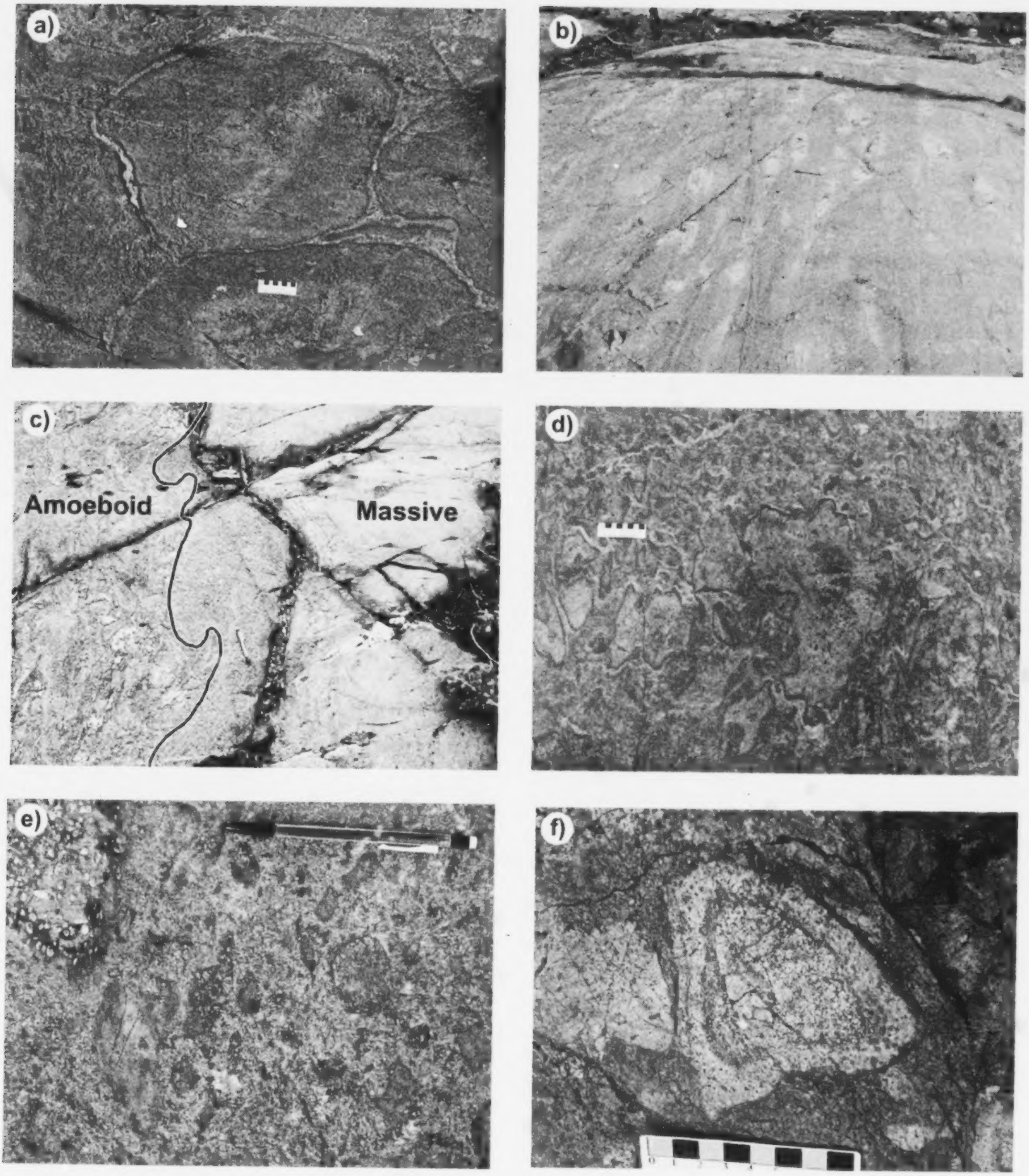


Figure GS-1-5: *Outcrop photographs of the Hidden formation rocks in the Schist Lake–Mandy mines area:* ***a)*** *closely packed aphyric pillows showing concentric thermal contraction cracks;* ***b)*** *massive aphyric basalt flow showing elongated epidote-quartz alteration patches (tops to the left);* ***c)*** *massive to pillowed basalt flow with a well-developed amoeboid top breccia (tops to the left);* ***d)*** *amoeboid pillow breccia composed of poorly sorted, subangular, highly vesicular to scoriaceous fragments of amoeboid pillows; note the darker chilled margin around the fragments;* ***e)*** *heterolithic mafic volcanic breccia composed of subangular, amygdaloidal aphyric basalt (upper left corner), aphyric nonamygdaloidal basalt (middle left) and sparsely plagioclase-phyric basalt (lower centre) in plagioclase-crystal-rich matrix;* ***f)*** *angular felsic-cored clast with mafic scoriaceous envelopes in heterolithic mafic volcanic breccia. Pencil for scale (14 cm long).*

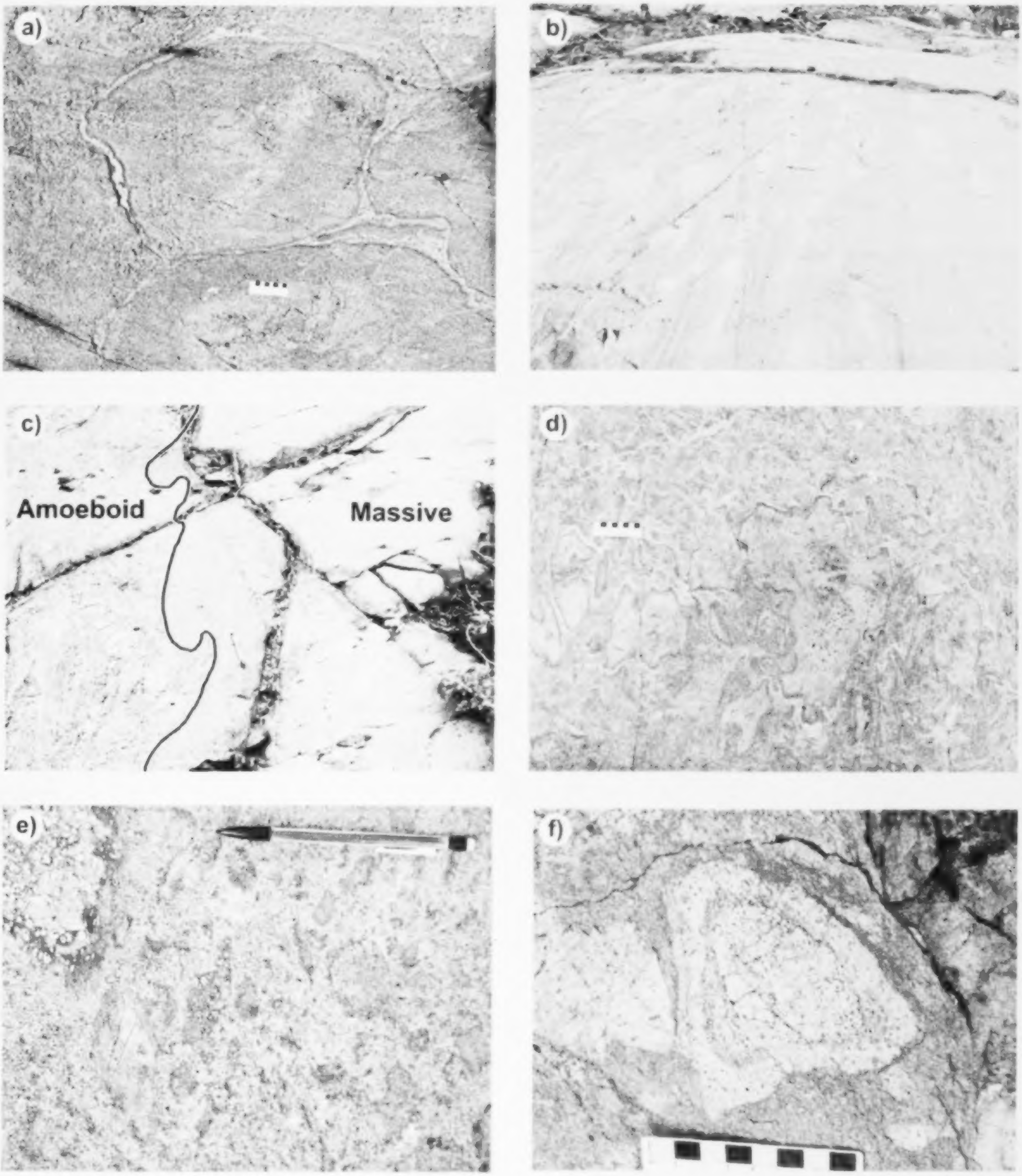


Figure GS-1-5: *Outcrop photographs of the Hidden formation rocks in the Schist Lake–Mandy mines area:* ***a)*** *closely packed aphyric pillows showing concentric thermal contraction cracks;* ***b)*** *massive aphyric basalt flow showing elongated epidote-quartz alteration patches (tops to the left);* ***c)*** *massive to pillowed basalt flow with a well-developed amoeboid top breccia (tops to the left);* ***d)*** *amoeboid pillow breccia composed of poorly sorted, subangular, highly vesicular to scoriaceous fragments of amoeboid pillows; note the darker chilled margin around the fragments;* ***e)*** *heterolithic mafic volcanic breccia composed of subangular, amygdaloidal aphyric basalt (upper left corner), aphyric nonamygdaloidal basalt (middle left) and sparsely plagioclase-phyric basalt (lower centre) in plagioclase-crystal-rich matrix;* ***f)*** *angular felsic-cored clast with mafic scoriaceous envelopes in heterolithic mafic volcanic breccia. Pencil for scale (14 cm long).*

medium green on fresh surfaces. It is mainly massive, clast supported and very poorly sorted in the north and the east. To the west and south, however, it is crudely bedded to bedded, matrix supported and shows a greater proportion of lapilli breccia and lapilli tuff (Figure GS-1-5e). These breccia beds commonly show normal grading but also display rare reverse grading.

Fragments are poorly sorted, subangular to angular, and range in size from <0.5 to 60 cm. All fragments are mafic in composition but vary in texture: buff brown to beige-green aphyric basalt; buff brown to green amygdaloidal (5–35% of 0.5–4 mm quartz-filled amygdules) aphyric basalt; pillowed basalt fragments still showing part of their chilled margin; dark reddish brown, chilled, pillow margin fragments; scoriaceous basaltic fragments; rare plagioclase-phyric amygdaloidal to nonamygdaloidal basalt; and a few felsic-cored clasts with mafic scoriaceous envelopes (Figure GS-1-5f). The matrix of the heterolithic breccia is poorly sorted and characteristically plagioclase-crystal rich (10–30% plagioclase, 1–5 mm in size).

The unit displays an overall fining to the south and west. The high angularity of the contained fragments and local preservation of fragments with fragile structures, such as scoriaceous and cored clasts, suggest they underwent a minimum amount of transport and likely were derived from a local source. The abrupt transition from mainly flows in the north to mainly breccia in the south along a series of northwest-trending faults just southeast of Carlisle Lake suggests that these faults may be synvolcanic in origin. For this reason, the heterolithic breccia is interpreted to be the product of debris flows deposited in a fault-bounded subsidence structure from local sources to the north. The cored clasts, with scoriaceous envelopes, are typical of spatter deposit. Because they were only observed in proximity to the transition area, the fault structures may have localized some 'fountaining' volcanism.

Mafic tuff

Thin (<3 m), well-bedded, fine-grained mafic tuff intervals are found here and there intercalated with the mafic flows of the Hidden formation. They are usually thinly bedded mafic mudstone and siltstone, and commonly show normal grading. One fairly continuous 2 m thick interval of this mafic mudstone and siltstone forms the uppermost unit of the Hidden formation on the peninsula in Potter Bay, just east of the Manitoba-Saskatchewan border.

Thin-bedded, tuffaceous 'sand-silt couplets' and graded beds are taken to suggest a resedimented origin for these rocks. They may represent turbidite deposits in an unstable volcanic environment. They also mark periods where a hiatus or quiescence in volcanism occurred.

Synvolcanic and younger mafic and felsic magmatism

The rocks of the Hidden formation are cut by several generations of mafic and felsic dikes. Numerous plagioclase-pyroxene-phyric and aphyric mafic dikes, trending 315 to 340°, cut across the flows. These dikes are in turn cut by plagioclase-quartz-phyric rhyolite dikes trending 000 to 015°. The latter cut across all units of the Hidden formation and, locally, faults that offset the stratigraphy on the east side of Carlisle Lake. These felsic dikes are, in turn, cut by multiple, mainly aphyric mafic dikes trending 340 to 000°. Distinguishing between the first and second generations of mafic dikes is not generally possible in the field.

Northwest-trending felsic dikes in the area are interesting, as some of them locally run parallel to and along 'synvolcanic' faults southeast of Carlisle Lake. These thin felsic dikes are usually also associated with multiple mafic dikes that trend in the same direction. Mafic dikes locally form very closely packed intrusive complexes to the east, with <10% of screens (1–5 m^2) of the host rocks visible. Mafic dikes similar to those in this intrusive complex cut across pillowed flows on the north side of the complex. These dikes locally inject interpillow spaces, suggesting that their emplacement occurred prior to induration of the interpillow material. Up-section, the dike complex ceases to be present and its termination is marked by a small quartz-plagioclase-phyric rhyolite lobe. The rhyolitic lobe, which has felsic breccia just below it, is interpreted to be part of a small extrusive dome (Figure GS-1-6a). A gossan zone is associated with the rhyolite dome to the south. This mafic-felsic dike complex is interpreted to be a synvolcanic dike swarm emplaced along synvolcanic subsidence faults.

Comparison of Hidden formation at Flin Flon to the Schist Lake–Mandy mines area

The Hidden formation stratigraphy directly overlying the Flin Flon–Callinan–Triple 7 ore deposits is a 400 to 880 m succession of thick, aphyric and plagioclase-phyric, mainly pillowed and massive basaltic flows that average 30 m in thickness. They are intruded by abundant mafic sills and dikes, and interlayered with minor mafic volcaniclastic rocks (Figure GS-1-4a; DeWolfe and Gibson, GS-2, this volume, Tardif, 2003; DeWolfe and Gibson, 2005; Gibson, unpublished data 2000–2006, DeWolfe, unpublished data, 2004–2006). The abundance of thick flows and high volume of sills and dikes above the Flin Flon–Callinan–Triple 7 ore deposits suggest a vent-proximal setting for these volcanic rocks. They are interpreted as products of voluminous volcanism forming a shield volcano erupted during a period of resurgent basalt volcanism and subsidence (DeWolfe and Gibson, 2005). This shield volcanism immediately followed a hiatus in volcanism during which the Flin Flon–

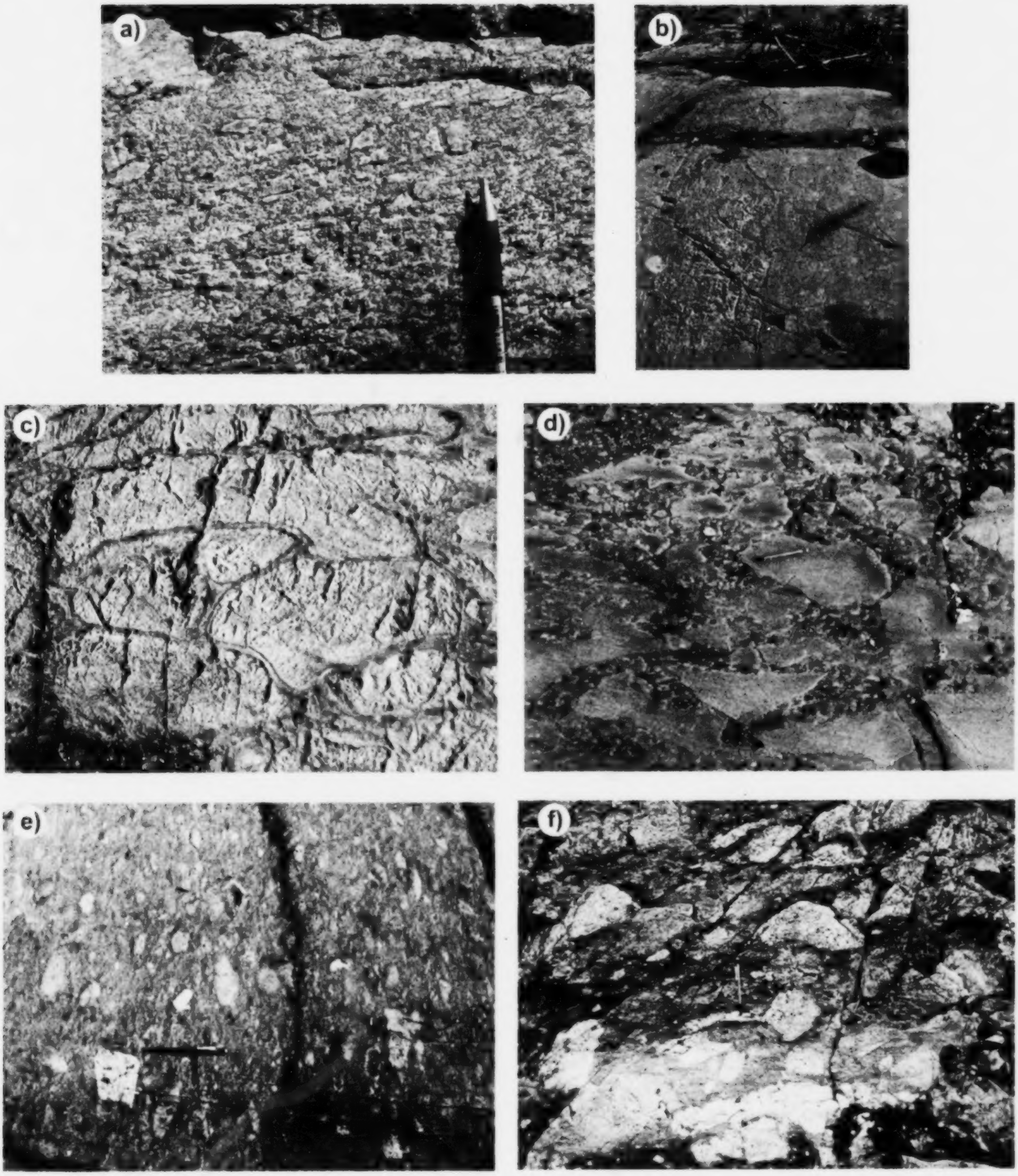


***Figure GS-1-6:** Outcrop photographs of the rocks in the Schist Lake–Mandy mines area: **a)** poorly sorted, massive felsic breccia associated with a rhyolite lobe, Hidden formation; **b)** undulating basal contact of massive coarse-grained flows of the Louis formation (to the right) sinking into monolithic flow-top breccia of the underlying flow (tops to the right); **c)** nicely shaped pillowed flows of the Louis formation (tops to the right); **d)** clast-supported, massive, poorly sorted, heterolithic, mafic volcanic breccia east of the Mandy Road Fault; **e)** matrix-supported, massive, poorly sorted, heterolithic mafic and felsic breccia east of the Mandy Road Fault, showing very angular, light-coloured felsic clasts mixed with subrounded mafic clasts; **f)** clast-supported, monolithic felsic breccia east of the Mandy Road Fault. Pencil for scale (14 cm long).*

Callinan–Triple 7 VMS deposits were formed (DeWolfe and Gibson, 2005).

In the Schist Lake–Mandy mines area, the Hidden formation flows are generally thinner and accompanied by volumetrically minor synvolcanic dikes and sills. This suggests a less proximal volcanic environment, farther away from the main vent of the Hidden formation shield volcano, than that directly above the Flin Flon–Callinan–Triple 7 VMS deposits. The presence of Hidden formation synvolcanic subsidence structure(s) in the Schist Lake–Mandy mines area, marked by abundant breccia and associated mafic and felsic magmatism-volcanism, is unique in the Flin Flon area. It most likely represents a small subsidence structure on the side of the main volcanic edifice that is centred on the Flin Flon area.

Louis formation

In the Schist Lake–Mandy mines area, rocks of the Louis formation are exposed on the peninsula between Phantom and Burley lakes, and extend south to the east tip of Green Lake and west to the Burley Lake Fault (Figure GS-1-3). These rocks were previously mapped as porphyritic andesite (unit 2) by Stockwell (1960) and as the plagioclase-phyric and glomerophyric flows of the Burley Lake basaltic andesite (unit 3a) by Bailes and Syme (1989).

The Louis formation rocks in the Schist Lake–Mandy mines area consist mainly of plagioclase-pyroxene-phyric basalt flows intercalated with a lesser amount of aphyric and plagioclase-phyric basalt flows and mafic volcaniclastic rocks, as well as quartz-plagioclase-phyric rhyolite flows and associated felsic breccia at the base of the formation (Figure GS-1-4). The rocks form a subvertical to steeply dipping, thick, continuous volcanic stratigraphic sequence that trends north-northwest and faces west. An exception to this is the southernmost exposures of the Louis formation east of Green Lake, where a faulted wedge faces east (Figure GS-1-3). The western, upper part of the Louis formation is faulted by the Burley Lake Fault. The maximum observed thickness of the Louis formation in the Schist Lake–Mandy mines area is <400 m, near Phantom Lake in the north, decreasing to <100 m at Green Lake in the south (Figure GS-1-3).

Rhyolite flows

Massive to locally brecciated, plagioclase-quartz-phyric rhyolite flows conformably overlie well-bedded mafic tuff of the Hidden formation to the east, and define the base of the Louis formation on the peninsula between Phantom and Burley lakes (Figure GS-1-3). This rhyolite dome is composed of at least two flows (each 20–30 m thick) that show internal autobrecciation and flow banding. The flows weather light beige to white and are medium grey on fresh surfaces. This felsic dome is faulted off to the north and thins to the south. It is conformably overlain by basaltic flows to the west. No other felsic rocks were observed in the Louis formation in the map area.

Basaltic flows

Louis formation basaltic flows in the Schist Lake–Mandy mines area usually weather buff brown to brown, and are dark green on fresh surfaces. They constitute more than 90% of the Louis formation rocks in the area.

Plagioclase-pyroxene-phyric flows

The majority of the Louis formation basalt flows (>70%) are plagioclase-pyroxene phyric, with 10 to 12% plagioclase phenocrysts (1–3 mm) and 3 to 7% pyroxene phenocrysts (0.5–3 mm). Flows are generally very thick (up to 80 m) and show thick (20–50 m), massive, coarse-grained (2–4 mm pyroxene and plagioclase crystals) bases with thin (1–10 m) pillowed and/or amoeboid pillowed and breccia tops. Where exposed, the basal contact of these massive coarse-grained flows is undulating and, in places, shows a 1 to 2 m thick chilled margin (fine- to medium-grained equigranular texture) with 10 to 20 cm long pipe vesicles perpendicular to the basal contact (Figure GS-1-6b). Up-section, the massive part of the flow becomes finer grained and increasingly porphyritic. Where the flows become fine grained to porphyritic, epidote-quartz patches appear along with quartz-filled amygdules; they increase in abundance and size toward the top of the flows. The overlying pillows are 40 to 80 cm in size and usually amygdaloidal, and some display concentric thermal contraction cracks (Figure GS-1-6c).

To the south, near the contact with the Hidden formation aphyric flows, the plagioclase-pyroxene-phyric flows of the Louis formation are thinner (5–10 m) and lack a thick, coarse-grained massive base. The pillows are generally larger (40–150 cm), in places showing megapillows up to 3 m in size.

Aphyric and plagioclase-phyric flows

Aphyric and plagioclase-phyric flows are intercalated in places with the plagioclase-pyroxene-phyric flows, especially to the north. These flows average 10 to 30 m in thickness and are massive to pillowed, with various amounts of quartz-filled amygdules. Pillows are usually closely packed, with <5% interpillow material (hyaloclastite). They average 40 to 80 cm in size, with 1 to 2 cm thick, dark green chilled margin. Some show concentration of amygdules in their upper portion, or concentric thermal contraction cracks, or both.

Mafic volcaniclastic rocks

Minor, thin, well-bedded, fine-grained mafic tuff intervals (<3 m) are intercalated with the mafic flows of the Louis formation. They are usually thinly bedded mafic mudstone and siltstone.

Synvolcanic gabbroic intrusions

On the northernmost part of the peninsula between Phantom and Burley lakes, massive, aphyric to sparsely porphyritic flows of the Louis formation appear to grade into massive, medium- to coarse-grained, equigranular to slightly plagioclase- and pyroxene-phyric gabbro intrusions.

Comparison of the Louis formation at Flin Flon to the Schist Lake–Mandy mines area

The Louis formation stratigraphy in the Flin Flon camp is localized in the core of the north-northwest-trending Burley Lake syncline. Its total observed thickness varies from <200 m on the west limb to greater than 800 m in the nose of the fold at Louis Lake, just south of the town of Flin Flon (DeWolfe, pers. comm., 2006).

The Louis formation rocks and stratigraphy are very similar at Flin Flon and in the Schist Lake–Mandy mines area. In both places, the formation is composed mainly of plagioclase-pyroxene-phyric basaltic flows, with minor aphyric and plagioclase-phyric basaltic flows, mafic volcaniclastic rocks, and local rhyolite flows and associated felsic volcaniclastic rocks near the base (Figure GS-1-4). One small difference is that the basaltic flows in the Flin Flon camp are generally thinner (averaging 15 m and ranging up to 60 m; DeWolfe, pers. comm., 2006) than those in the Schist Lake–Mandy mines area (averaging 50 m and ranging up to 80 m).

The main difference between Louis formation rocks at Flin Flon and those in the Schist Lake–Mandy mines area is that the former are exposed in the core of the Burley Lake syncline, whereas the latter form a single, homoclinal, west-facing sequence. Further work is required to define the location of the Burley Lake syncline as it extends south into the Schist Lake–Mandy mines area.

Undivided volcanic rocks

The rocks east of the Mandy Road Fault and west of the Burley Lake Fault are not yet assigned to any existing stratigraphic unit in the Flin Flon camp; more field and analytical work is required before doing so.

West of the Burley Lake Fault

Rocks west of the Burley Lake Fault are poorly exposed (<10% exposure). In the southwestern portion of the map area around the Green Lake Fault, the rocks become more hornfelsed, and foliations and delicate primary textures are less commonly observed. Just north and west of Green Lake, several pink feldspar-quartz-phyric porphyry dikes (1–3 m wide) were observed trending northwest to north-northwest.

North of the Green Lake Fault, the rocks consist of subvertical to vertical, northwest-trending, east-facing, thin, aphyric, plagioclase-phyric and plagioclase-pyroxene-phyric basalt flows that are typically intercalated with thin units of well-bedded mafic tuff and local heterolithic breccia. A north-northeast-trending fault west of Green Lake breaks these volcanic rocks into two slightly different packages.

Along Burley Lake, north of the north-northeast-trending fault, the basaltic flows are slightly plagioclase phyric (<2%, <1 mm in size), weather buff brown to dark brown and are dark green on fresh surfaces. Basalt flows in the area are thin (1–5 m thick) and are locally interbedded with thin (<1 m thick), well-bedded mafic tuff. Flows are usually massive at their base, and amygdule abundance increases toward the top. Some massive flows show a 3 to 10 cm thick frothy top overlain by 0.3 to 3 m thick monolithic flow-top breccia. Other massive flows display a >5 m thick pillowed top, with pillows slightly flattened and up to 1.5 m long and 60 cm high. Pillows in these flows have a 1.5–2 cm, dark green chilled margin and are amygdule rich toward their tops (~10%, up to 0.7 cm in size). Most flows in the area show disseminated pyrite in both massive and pillowed facies.

To the southwest, toward the Green Lake Fault, the basalt flows are plagioclase-pyroxene phyric (7–10% plagioclase, 0.2–1.5 mm; 5% pyroxene, 0.2–2.5 mm), weather dark brown to very dark green, and are dark green to black on fresh surfaces. These rocks are hornfelsed, highly fractured and shattered by numerous epidote-quartz veins <0.5 mm thick. The flows are massive and contain 5 to 10% round quartz-amygdules 0.5 to 3 cm in diameter.

South of the north-northeast-trending fault, rocks along Burley Lake form a 100 m thick package of aphyric, medium- to fine-grained, 5 to 10 m thick massive flows with local mafic sills and intercalations of thin, well-bedded mafic tuff (1–3 m thick). Massive flows show epidote-quartz patches, which increase in abundance toward the flow top, and an upward decrease in grain size. The well-bedded mafic tuffaceous rocks consist of locally graded, finely bedded mafic siltstone (medium green) and mudstone (light green to beige), and constitute <10% of the rocks.

South of this package, the rocks north of Green Lake consist of massive to pillowed plagioclase-phyric basalt flows and local pyroxene-plagioclase-phyric or aphyric varieties. They are locally interbedded with thin, well-bedded mafic tuff and mafic breccia. In places, well-exposed sequences of massive to pillowed to amoeboid brecciated flows are exposed, but lack of exposure limits observation of complete flows and prevents thorough description of the volcanic sequence in this area. Similar to other areas, massive flows display epidote-quartz patches that increase in abundance and size toward the flow top. Pillows are 50 to 80 cm in size with <1.5 cm thick, dark green, chloritic chilled margins and local epidote-quartz alteration patches. Rare exposures of pillows with no chilled margin and well-developed concentric thermal contraction cracks were observed.

East of Mandy Road Fault

The rocks east of the Mandy Road Fault on the west shore of the Schist Lake are of considerable interest as they host the past-producing Schist and Mandy VMS mines. Only part of this area was remapped during the 2006 field season, as they are the focus of a new M.Sc. thesis by E. Cole at Laurentian University under the supervision of H. Gibson and S. Piercey.

Overall, the rocks east of the Mandy Road Fault consist of three or more faulted packages of vertical to subvertical, north-trending and west-facing volcanic rocks. The faults bounding these rock packages are not well exposed (beneath roads or lakes). The rocks are overall moderately to highly deformed, with one to three well-developed foliations.

Volcanic breccia units

Two heterolithic mafic breccia units, one heterolithic mafic and felsic breccia unit, and one felsic breccia unit have been observed east of the Mandy Road Fault. The two heterolithic mafic breccia units are restricted to the northern part of the map area, whereas the felsic breccia units are restricted to the south.

The northernmost heterolithic mafic breccia, east of the west and east arms of the Mandy Road Fault and west of the minesite road, consists of massive, poorly sorted, usually clast-supported lapilli breccia to breccia. Clasts are angular to subangular and range in size from 1 to 50 cm. They are all mafic in composition but vary in texture and colour: light to medium green and brown, amygdaloidal to nonamygdaloidal aphyric basalt; brownish, plagioclase-phyric amygdaloidal basalt; and dark reddish brown, aphyric, amygdaloidal to nonamygdaloidal basalt (pillow fragments, chilled margin pieces?). The matrix, which is usually plagioclase-crystal rich, is poorly sorted and composed of lapilli-size fragments of similar composition to that of the contained clasts.

The other heterolithic mafic breccia unit, on the east side of the east arm of the Mandy Road Fault, consists of massive to well-bedded, poorly sorted, clast- to matrix-supported lapilli breccia to breccia with lapilli to tuffaceous bed intervals (Figure GS-1-6d). It is locally intercalated with aphyric basaltic flows (*see* description below). Clasts in this breccia unit are angular to subrounded and range in size from 0.5 to 60 cm in clast-supported beds and 3 to 15 cm in matrix-supported beds. Contained clasts are all mafic in composition, but vary in texture and colour: dark brown to green to light green to beige, aphyric, amygdaloidal to nonamygdaloidal basalt; sparsely plagioclase-phyric to plagioclase-phyric basalt; scoriaceous mafic clasts; and pillow fragments. The matrix is poorly sorted and composed of lapilli and finer grained fragments of composition similar to that of the larger clasts. In places along the shore of Schist Lake, this unit is altered and hematized (dark purple clasts in light green chloritic matrix).

The heterolithic mafic and felsic volcanic breccia unit is poorly exposed in the map area, and restricted to a small peninsula on the shore of Schist Lake, as well as small islands in the southernmost part of the area. It consists of massive, poorly sorted, clast-supported breccia with angular to subrounded clasts of dark green to beige, plagioclase-phyric, amygdaloidal to nonamygdaloidal basalt; dark green to beige, aphyric, amygdaloidal to nonamygdaloidal basalt; beige scoriaceous mafic clasts; beige aphyric rhyolite; and pinkish plagioclase-phyric rhyolite (Figure GS-1-6e). The felsic clasts usually represent <15% of the clast content and are very angular. The matrix to the breccia is usually chloritic and rich in plagioclase crystals (up to 30%, 1–4 mm in size). On the southernmost peninsula, this breccia unit is interbedded with well-bedded mafic siltstone and mudstone.

Felsic volcanic breccia is exposed on the northern tip of one island on Schist Lake. It consists of very angular, aphyric, massive rhyolitic clasts and blocks of well-bedded felsic tuff (up to 50 cm long) in a beige-grey, fine-grained felsic matrix (Figure GS-1-6f).

Mafic volcaniclastic rocks

A 200 m thick package of well-bedded, fine- to coarse-grained mafic sandstone, siltstone and mudstone occurs between the east and west arms of the Mandy Road Fault. These mafic volcaniclastic rocks are usually thinly bedded and commonly show normal grading. They also show small- and large-scale S-folds that plunge gently to the southeast. These folds could be related to the faults in the area (drag folds?).

Basaltic flows

A package of ~150 m of aphyric to sparsely plagioclase-phyric, massive, pillowed and amoeboid basalt flows is intercalated with the heterolithic breccia north of the Schist and Mandy minesites. The pillows are amygdaloidal and show very irregular shapes (amoeboid), with up to 30% disrupted and shattered, very fine grained, interpillow mafic sedimentary rocks (peperite?). Plagioclase-phyric massive basaltic flows were observed in two locations south of the aphyric flows. The southernmost occurrence on a small island south of the Schist and

Mandy minesites is crosscut by small shear zones and shows disseminated 1 to 3 cm pockets of pyrrhotite.

Economic considerations

Volcanogenic massive sulphide (VMS) deposits in the Flin Flon area occur in association with the felsic volcanic units in synvolcanic collapse structures and calderas, within the main mafic volcanic complex (Bailes and Syme, 1989; Syme and Bailes, 1993). The ability to recognize these structures is key to exploring for VMS deposits in and around the Flin Flon area, as well as in other greenstone belts in Manitoba.

This summer's 1:5000 scale bedrock mapping of the Schist Lake–Mandy mines area has identified a potential subsidence structure complete with associated synvolcanic faults and local fault-associated mafic and felsic magmatism. This structure, within the Hidden formation rocks just southeast of Carlisle Lake, also has a spatially associated and well-developed gossan. Other smaller gossans were observed in the area, often associated with mafic and felsic dikes.

Until recently, rocks of the Hidden formation occurring in the hangingwall to the Flin Flon–Callinan–Triple 7 VMS deposits were never considered as a serious exploration target. The recent mapping at both Flin Flon (DeWolfe and Gibson, GS-2, this volume) and in the Schist Lake–Mandy mines area, however, clearly shows that the hangingwall stratigraphy possesses the very same volcanic structures that focused mineralization and ore formation in the underlying Flin Flon formation. Thus, these rocks should be and are being re-evaluated in terms of their exploration potential.

Acknowledgments

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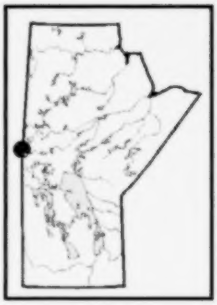
GS-2 Stratigraphic subdivision of the Hidden and Louis formations, Flin Flon, Manitoba (NTS 63K16SW)

by Y.M. DeWolfe[1] and H.L. Gibson[1]

DeWolfe, Y.M. and Gibson, H.L. 2006: Stratigraphic subdivision of the Hidden and Louis formations, Flin Flon, Manitoba (NTS 63K16SW); *in* Report of Activities 2006, Manitoba Science, Technology, Energy and Mines, Manitoba Geological Survey, p. 22–34.



Summary

The hangingwall to the Flin Flon volcanogenic massive sulphide (VMS) deposits, which consists of basaltic flows, sills and volcaniclastic rocks with subordinate rhyolitic flows and volcaniclastic rocks, can be subdivided into two formations, the Hidden formation and the Louis formation. The contact between the Hidden and Louis formations is marked by mafic tuff that represents a significant and mappable hiatus in volcanism traceable throughout the Flin Flon area.

The Hidden formation defines the onset of hangingwall volcanism and comprises, from oldest to youngest, the 1920 unit, the Reservoir member and the Stockwell member. The 1920 unit comprises massive, pillowed and peperite facies basalt flows and is overlain locally by felsic or undifferentiated volcaniclastic rocks. The Reservoir member, which conformably overlies the 1920 unit, comprises massive, pillow, breccia and peperite facies basalt flows. It is conformably overlain by the Stockwell member, which comprises massive, pillowed and breccia facies basalt flows and is locally overlain by mafic volcaniclastic rocks.

The Louis formation conformably overlies the Hidden formation and consists of the Tower and Icehouse members, as well as undivided basaltic flows. The Tower member occurs at the base of the Louis formation and consists of massive to in situ–brecciated, aphyric rhyolite and associated volcaniclastic rocks. The Icehouse member, which conformably overlies the Tower member, consists of massive, pillowed and volcaniclastic facies basalts that are conformably overlain by undivided basaltic flows.

A number of features suggest a synvolcanic graben located on the west limb of the Hidden syncline and another in the area between Sipple hill and Louis lake. These include rapid thickness and facies variations within the 1920 unit of the Hidden formation, north of the Railway Fault, and in the Icehouse member of the Louis formation, between Sipple hill and Louis lake. The occurrence of volcaniclastic rocks within these formations that correspond to the thickest parts of the 1920 unit and Icehouse member suggests infilling of a depositional basin and is consistent with the interpreted synvolcanic graben. Also consistent with a graben in the Hidden formation north of the Railway Fault is the presence of large (up to 20 m by 10 m) domains of massive facies surrounded by pillows in flows of both the Reservoir and Stockwell members. These domains are interpreted to be large lava tubes emanating from a proximal magma source. This is corroborated by a high abundance of synvolcanic basaltic dikes and sills within the 1920 unit, Reservoir member and Stockwell member in the section where thick flows, abundant volcaniclastic rocks and the tube-fed flows occur.

Economic considerations with respect to the Hidden and Louis formations include the following:

- Faults controlling the locations of the grabens were likely active during the volcanism that formed the Flin Flon, Hidden and Louis formations, and therefore may have controlled massive sulphide mineralization in the underlying Flin Flon formation.
- Thrust faults repeating the Hidden formation may also structurally repeat the underlying Flin Flon mine horizon.
- Volcaniclastic units overlie the 1920 unit, separate the numerous flows within the Stockwell member, mark the contact between the Hidden and Louis formations, and separate flows within the Louis formation. They may be prospective along strike at depth because they represent hiatuses in volcanism, occur within topographic depressions, are in vent-proximal environments, and commonly correspond to areas of hydrothermal activity.

Introduction

The lateral extent and thickness of the Hidden and Louis formations, as determined from mapping (Stockwell, 1960; Bailes and Syme, 1989; Thomas, 1994), suggest that they are part of a voluminous basaltic volcano within the hangingwall of the Flin Flon, Callinan and Triple 7 VMS deposits (Figures GS-2-1, -2). A premise of this study is that these formations represent an integral part of the volcanic and subsidence history that characterizes the ore-forming environment at Flin Flon. Thus, reconstructing the volcanic architecture and the magmatic, subsidence and hydrothermal history of this basaltic volcano are primary objectives of this research.

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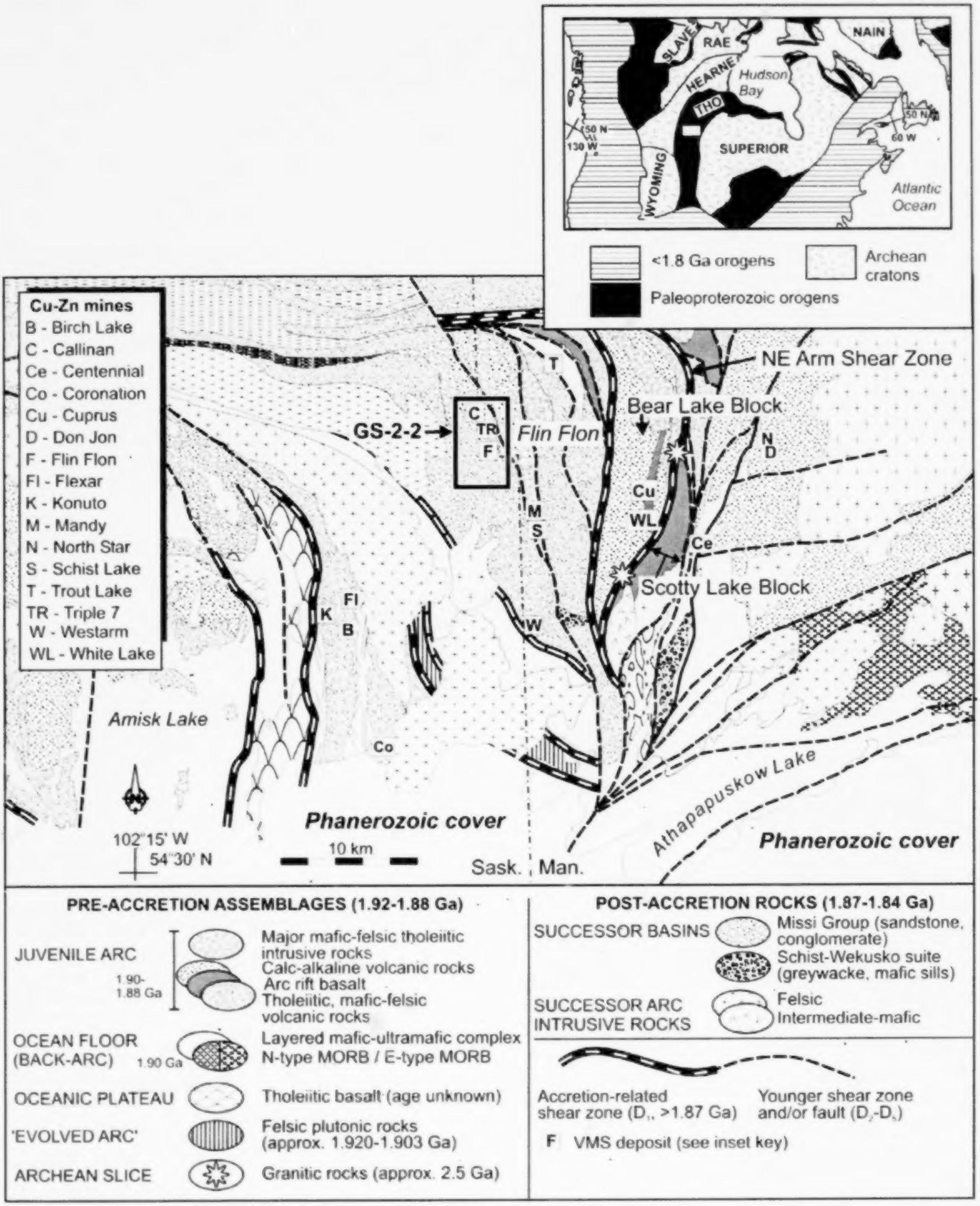
SLAVE
RAE
NAIN
HEARNE
Hudson Bay
THO
50 N
130 W
50 N
60 W
SUPERIOR
WYOMING
Atlantic Ocean
<1.8 Ga orogens
Archean cratons
Paleoproterozoic orogens
Cu-Zn mines
B - Birch Lake
C - Callinan
Ce - Centennial
Co - Coronation
Cu - Cuprus
D - Don Jon
F - Flin Flon
Fl - Flexar
K - Konuto
M - Mandy
N - North Star
S - Schist Lake
T - Trout Lake
TR - Triple 7
W - Westarm
WL - White Lake
GS-2-2
C
TR
F
Flin Flon
T
NE Arm Shear Zone
Bear Lake Block
N
D
Cu
WL
Ce
M
S
Scotty Lake Block
Fl
K
B
W
Amisk Lake
Co
Athapapuskow Lake
Phanerozoic cover
Phanerozoic cover
102°15' W
54°30' N
10 km
Sask.
Man.
PRE-ACCRETION ASSEMBLAGES (1.92-1.88 Ga)
JUVENILE ARC
1.90-1.88 Ga
Major mafic-felsic tholeiitic intrusive rocks
Calc-alkaline volcanic rocks
Arc rift basalt
Tholeiitic, mafic-felsic volcanic rocks
OCEAN FLOOR (BACK-ARC)
1.90 Ga
Layered mafic-ultramafic complex
N-type MORB / E-type MORB
OCEANIC PLATEAU
Tholeiitic basalt (age unknown)
'EVOLVED ARC'
Felsic plutonic rocks (approx. 1.920-1.903 Ga)
ARCHEAN SLICE
Granitic rocks (approx. 2.5 Ga)
POST-ACCRETION ROCKS (1.87-1.84 Ga)
SUCCESSOR BASINS
Missi Group (sandstone, conglomerate)
Schist-Wekusko suite (greywacke, mafic sills)
SUCCESSOR ARC INTRUSIVE ROCKS
Felsic
Intermediate-mafic
Accretion-related shear zone (D1, >1.87 Ga)
Younger shear zone and/or fault (D2-D3)
F VMS deposit (see inset key)

***Figure GS-2-1:** Geology of the Flin Flon Belt, showing the locations of known volcanogenic massive sulphide (VMS) deposits (modified from Syme et al., 1996); box indicates area covered by Figure GS-2-2; inset map shows the location of the Flin Flon Belt within the Trans-Hudson Orogen (THO).*

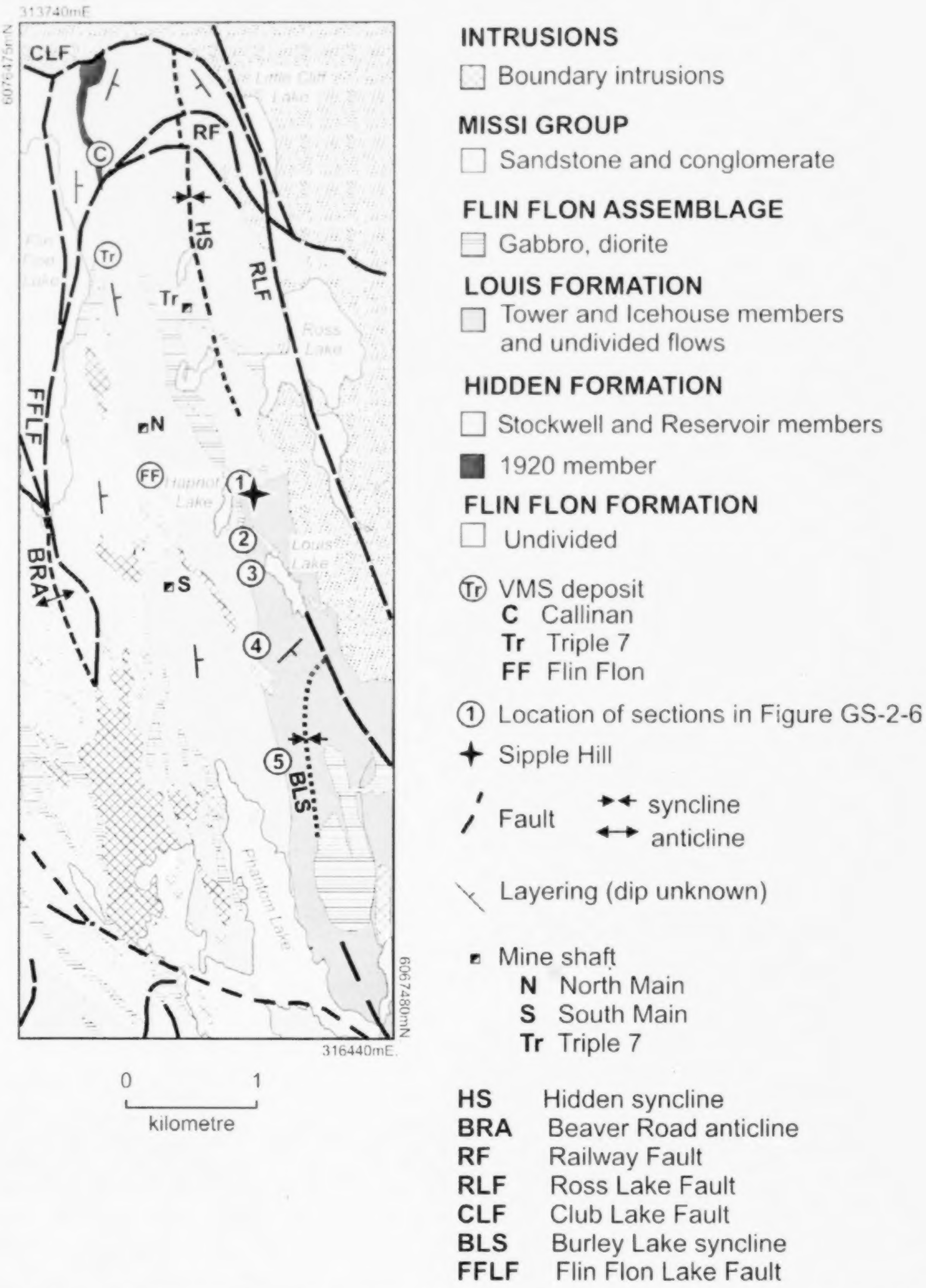
313740mE
6067475mN
6067480mN
316440mE
CLF
RF
HS
RLF
FFLF
BRA
BLS
C
Tr
FF
N
S
1
2
3
4
5
Little Cliff Lake
Flin Flon Lake
Ross Lake
Hapnot Lake
Louis Lake
Phantom Lake
0
1
kilometre
INTRUSIONS
Boundary intrusions
MISSI GROUP
Sandstone and conglomerate
FLIN FLON ASSEMBLAGE
Gabbro, diorite
LOUIS FORMATION
Tower and Icehouse members and undivided flows
HIDDEN FORMATION
Stockwell and Reservoir members
1920 member
FLIN FLON FORMATION
Undivided
VMS deposit
C Callinan
Tr Triple 7
FF Flin Flon
Location of sections in Figure GS-2-6
Sipple Hill
Fault
syncline
anticline
Layering (dip unknown)
Mine shaft
N North Main
S South Main
Tr Triple 7
HS Hidden syncline
BRA Beaver Road anticline
RF Railway Fault
RLF Ross Lake Fault
CLF Club Lake Fault
BLS Burley Lake syncline
FFLF Flin Flon Lake Fault

Figure GS-2-2: *Preliminary geology of the Flin Flon area* (modified from *Stockwell, 1960*); see *Figure GS-2-1* for *location.*

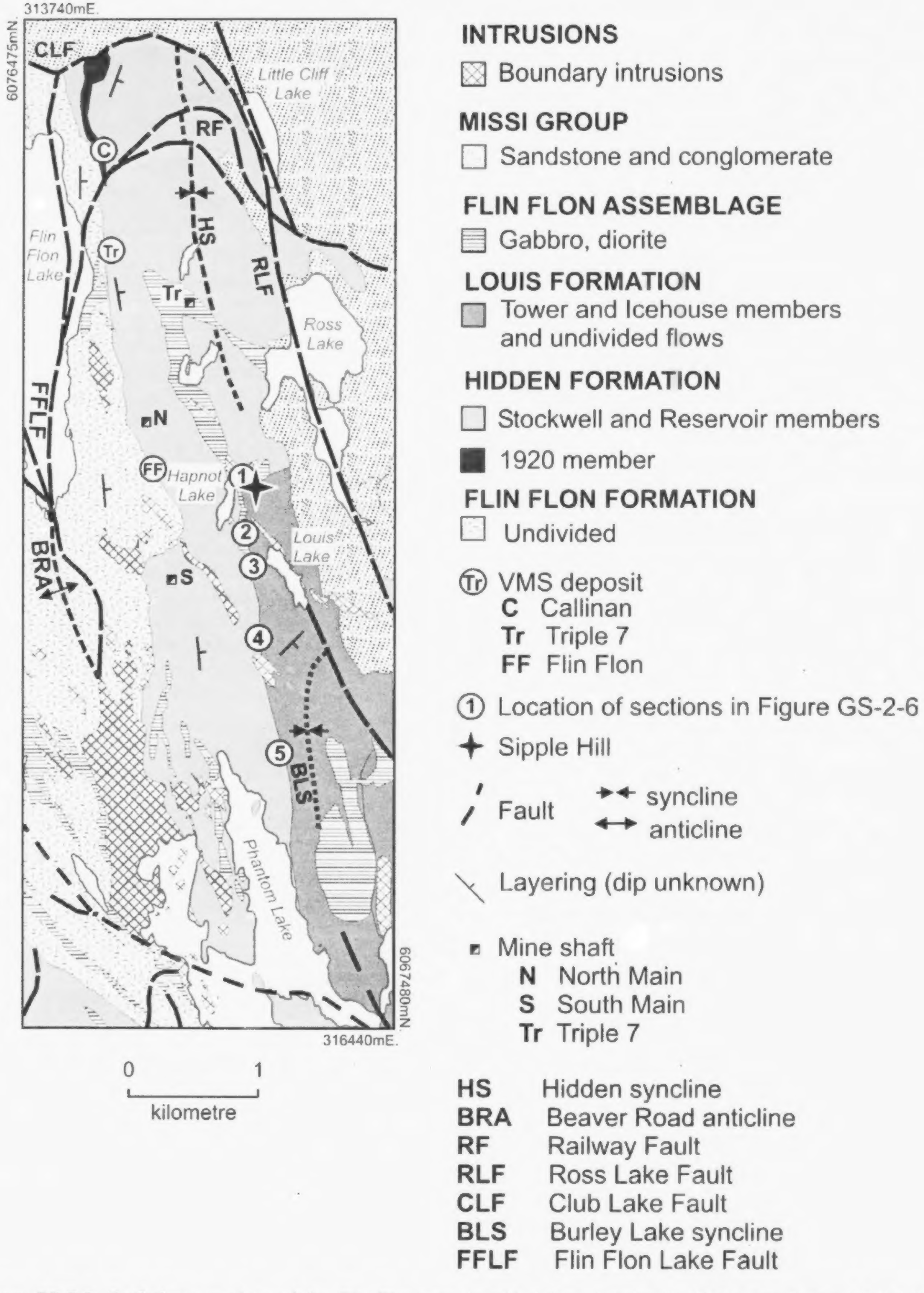
313740mE.
6076475mN
CLF
Little Cliff Lake
RF
C
HS
Flin Flon Lake
Tr
RLF
Tr
Ross Lake
FFLF
N
FF
Hapnot Lake
1
2
Louis Lake
3
S
BRA
4
5
BLS
Phantom Lake
6067480mN
316440mE.
0
1
kilometre
INTRUSIONS
Boundary intrusions
MISSI GROUP
Sandstone and conglomerate
FLIN FLON ASSEMBLAGE
Gabbro, diorite
LOUIS FORMATION
Tower and Icehouse members and undivided flows
HIDDEN FORMATION
Stockwell and Reservoir members
1920 member
FLIN FLON FORMATION
Undivided
VMS deposit
C Callinan
Tr Triple 7
FF Flin Flon
Location of sections in Figure GS-2-6
Sipple Hill
Fault
syncline
anticline
Layering (dip unknown)
Mine shaft
N North Main
S South Main
Tr Triple 7
HS Hidden syncline
BRA Beaver Road anticline
RF Railway Fault
RLF Ross Lake Fault
CLF Club Lake Fault
BLS Burley Lake syncline
FFLF Flin Flon Lake Fault

Figure GS-2-2: *Preliminary geology of the Flin Flon area* (modified from *Stockwell, 1960*); see *Figure GS-2-1* for location.

Identification of synvolcanic structures controlling Hidden and Louis formation volcanism may reveal hydrothermal conduits to buried VMS deposits. This will not only aid exploration in the Flin Flon area, but also add to the understanding of processes forming VMS deposits during evolution of submarine volcanic complexes.

The purpose of this paper is to provide a new stratigraphic subdivision for the Hidden and Louis formations that is mappable, reflects the volcanic history and petrogenesis of these formations, and clearly defines and subdivides the hangingwall sequence to the Flin Flon orebodies. This new proposed stratigraphic subdivision is based on detailed mapping over a three-summer field program, conducted at scales ranging from 1:500 to 1:2000, and focused on these two formations in the Flin Flon area. Lithofacies within the Hidden formation have been described in detail by DeWolfe and Gibson (2004, 2005) and therefore will only be summarized in this report. A preliminary description of lithofacies recognized within the Louis formation is provided herein.

Regional geology

The Paleoproterozoic Flin Flon greenstone belt is part of the southeastern Reindeer Zone of the Trans-Hudson Orogen and contains 27 known VMS deposits (Figure GS-2-1). The greenstone belt consists of a series of assemblages that range in age from 1.9 to 1.84 Ga (Stern et al., 1995) and include arc, back-arc, ocean-floor and successor-arc successions. The Flin Flon and Snow Lake ocean-arc assemblages contain the majority of the VMS deposits.

The study area is located around the town of Flin Flon in the Flin Flon arc assemblage. It is composed of juvenile metavolcanic rocks (1.91–1.88 Ga) that are unconformably overlain by successor-arc fluvial sedimentary rocks of the Missi Group (ca. 1.84 Ga). Rocks of the Flin Flon arc assemblage are interpreted to have been erupted and emplaced in an island-arc–back-arc setting (Syme and Bailes, 1993), and consist of basalt, basaltic andesite flows and breccia, with lesser rhyolite flows. The Flin Flon, Callinan and Triple 7 VMS deposits (Figure GS-2-2), which total more than 85.5 million tonnes grading 2.2% Cu, 4.3% Zn, 2.49 g/t Au and 38.16 g/t Ag, are interpreted to have formed during a period of localized rhyolitic volcanism in a synvolcanic subsidence structure, or caldera, within a much larger, dominantly basaltic, central volcanic complex (Bailes and Syme, 1989; Devine et al., 2002; Devine, 2003). The Hidden and Louis formations (Figure GS-2-2) are interpreted to have been erupted during a period of resurgent basalt volcanism and subsidence that immediately followed a hiatus in volcanism marked by VMS ore deposition.

Previous stratigraphic subdivisions and nomenclature proposed for the hangingwall Hidden and Louis formations

Several stratigraphic subdivisions and nomenclature systems have been proposed for the basaltic flows, sills and volcaniclastic rocks, and subordinate rhyolitic flows and volcaniclastic rocks occurring in the hangingwall to the Flin Flon VMS deposits. Stockwell (1960) subdivided the hangingwall succession based on lithological differences into aphyric and plagioclase-porphyritic andesitic and basaltic flows overlain by plagioclase- and pyroxene-porphyritic basaltic flows (Table GS-2-1). Bailes and Syme (1989), in turn, subdivided the hangingwall into

Table GS-2-1: Summary of previous stratigraphic subdivisions and nomenclature proposed for the Hidden and Louis formations, Flin Flon area.

Source	Dominantly aphyric basalt and andesite		Dominantly plagioclase porphyritic basalt	
	Formation names	Members	Formation names	Members
This report	Hidden formation	Stockwell member Reservoir member 1920 unit	Louis formation	Icehouse member Tower member
DeWolfe and Gibson (2004, 2005)	Hidden formation	Tower member Newcor member Bomber member 1920 member	Louis formation	
TGI-1 working group (Ames et al., 2003)	Hidden formation	Tower member Newcor member Bomber member 1920 member	Louis formation	
Ames et al. (2002)	Hidden formation	Tower member Reservoir member unnamed member '1920 member'	Louis formation	
Bailes and Syme (1989)	Hidden Lake basalt		Burley Lake basaltic andesite	

lower and upper units, the Hidden Lake basalt and Burley Lake basaltic andesite, respectively; however, they described the Hidden Lake basalt as dominantly plagioclase-porphyritic with thin aphyric and sparsely plagioclase-porphyritic flows, and the Burley Lake sequence as including basalt, basaltic-andesite and rarely andesite. Ames et al. (2002) retained the Hidden formation name and divided the formation into the '1920 member', an unnamed basaltic unit with peperite, interflow and interpillow sediment, the Reservoir member, and the Tower member (Table GS-2-1). Ames et al. (2002) considered the 'Tower member' to be the top of the Hidden formation. They termed the overlying sequence of feldspar-pyroxene-phyric basaltic flows and sills, and minor aphyric pillowed basalt, scoriaceous amoeboid breccia and scoriaceous lapilli tuff the Louis formation.

DeWolfe and Gibson (2004, 2005) and the Targeted Geoscience Initiative (TGI) I Working Group (unpublished map, 2003) further subdivided the Hidden formation, as defined by Ames et al. (2002), into the 1920, Bomber, Newcor, and Tower members (Table GS-2-1).

New stratigraphic subdivision and nomenclature for the Hidden and Louis formations

The summer of 2006 was the last of three field seasons in the Flin Flon area by M. DeWolfe, Ph.D. candidate at Laurentian University, that were aimed at documenting the hangingwall stratigraphy of the Flin Flon, Callinan and Triple 7 VMS deposits. During this project, detailed volcanic lithofacies mapping ranged in scale from 1:250 to 1:2000, and in stratigraphic position from the base of the Hidden formation, exposed in the western part of the town of Flin Flon, to the highest stratigraphic exposure of the Louis formation, in the core of the Burley Lake syncline east of Phantom Lake (Figure GS-2-2). The detailed lithofacies mapping also covered the entire length of the hangingwall stratigraphy to the VMS deposits. Based on this mapping, the authors propose a new coherent stratigraphic subdivision and nomenclature for the area that is mappable, reflects the volcanic history and petrogenesis of these rocks, and clearly defines and subdivides the hangingwall sequence to the Flin Flon orebodies.

Figure GS-2-3 schematically represents the new hangingwall stratigraphy of the Flin Flon orebodies (*modified from* Devine et al., 2002; Ames et al., 2002; Devine, 2003; DeWolfe and Gibson, 2004, 2005; Simard, GS-1, this volume). The formation names and distribution remain the same as the stratigraphic subdivisions and nomenclature for the basaltic and rhyolitic hangingwall succession, as first proposed by Bailes and Syme (1989) and as modified by Ames et al. (2002). The mafic tuff associated with the Tower member is an extensive unit representing a significant and mappable hiatus in volcanism that is widely distributed and readily recognized (Ames et al., 2003). For this reason, it better defines the top of the Hidden formation than the local Tower member rhyolite. This change, however, requires that the Tower member belong to the base of the Louis formation. The names of the Bomber and Newcor members of the Hidden formation (Thomas, 1994; DeWolfe and Gibson, 2005) are changed to the Reservoir and Stockwell members, respectively. This name change reflects the fact that the old definitions for these units (Thomas, 1989) are not applicable to the Hidden formation in its type section at Flin Flon, as they are derived from localities more than 3.5 km distant. As well, to comply with the North American Stratigraphic Code, the 1920 member is now termed the 1920 unit, as it is dominated (>95% by volume) by sills (cryptoflows).

Hidden formation

The Hidden formation consists, from oldest to youngest, of the 1920 unit (previously referred to as the 1920 member; DeWolfe and Gibson, 2004, 2005), the Reservoir member (previously referred to as the Bomber member; DeWolfe and Gibson, 2005) and the Stockwell member (previously referred to as the Newcor member; DeWolfe and Gibson, 2005).

The formation is dominated by basaltic and andesitic flows and intrusions, with minor interflow tuff and volcaniclastic rocks. Its exposed thickness ranges from 400 to 880 m, but determining this thickness accurately is complicated by D_1 thrust faulting and D_2 folding. The base of the Hidden formation is placed at the last occurrence of tuff and/or rhyolite of the underlying Millrock member of the Flin Flon formation, followed by 1) basaltic aphyric to sparsely (<5%) plagioclase-porphyritic flows and/or sills (Reservoir member), or 2) icelandite flows or sills (1920 unit; Figure GS-2-3).

The 1920 unit, which is thought to define the onset of Hidden formation volcanism, is restricted to the northwest limb of the Hidden syncline (Figure GS-2-2). It is recognized in the field by prominent acicular amphibole phenocrysts and is geochemically enriched in TiO_2, Fe_2O_3 and P_2O_5 compared with other mafic rocks in the Hidden formation. It has an average SiO_2 content of 55.50 wt. % and has been identified as icelandite by Wyman (1993). Stratigraphically, the 1920 unit occurs at the base of the Hidden formation, where it overlies volcaniclastic rocks of the Millrock member of the Flin Flon formation (Figure GS-2-3). The top of the 1920 unit is marked either by a felsic volcaniclastic unit and mafic sills of the Reservoir member, or by mafic volcaniclastic rocks overlain by plagioclase-porphyritic flows of the Stockwell member. The 1920 unit and these conformably overlying units are recognized in two distinct fault blocks separated by two northeast-striking thrust faults that structurally repeat the 1920 unit and the bounding basalt sills or flows (DeWolfe, 2005).

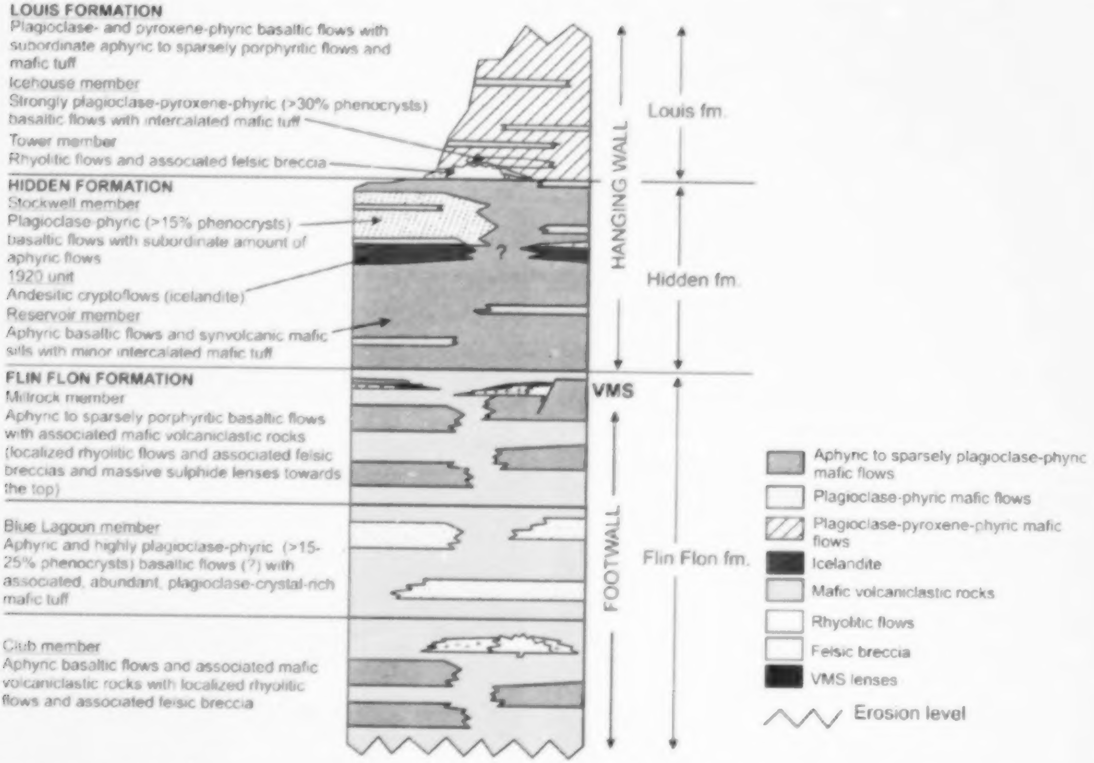
LOUIS FORMATION
Plagioclase- and pyroxene-phyric basaltic flows with subordinate aphyric to sparsely porphyritic flows and mafic tuff
Icehouse member
Strongly plagioclase-pyroxene-phyric (>30% phenocrysts) basaltic flows with intercalated mafic tuff
Tower member
Rhyolitic flows and associated felsic breccia
HIDDEN FORMATION
Stockwell member
Plagioclase-phyric (>15% phenocrysts) basaltic flows with subordinate amount of aphyric flows
1920 unit
Andesitic cryptoflows (icelandite)
Reservoir member
Aphyric basaltic flows and synvolcanic mafic sills with minor intercalated mafic tuff
FLIN FLON FORMATION
Millrock member
Aphyric to sparsely porphyritic basaltic flows with associated mafic volcaniclastic rocks (localized rhyolitic flows and associated felsic breccias and massive sulphide lenses towards the top)
Blue Lagoon member
Aphyric and highly plagioclase-phyric (>15-25% phenocrysts) basaltic flows (?) with associated, abundant, plagioclase-crystal-rich mafic tuff
Club member
Aphyric basaltic flows and associated mafic volcaniclastic rocks with localized rhyolitic flows and associated felsic breccia
?
HANGING WALL
VMS
FOOTWALL
Louis fm.
Hidden fm.
Flin Flon fm.
Aphyric to sparsely plagioclase-phyric mafic flows
Plagioclase-phyric mafic flows
Plagioclase-pyroxene-phyric mafic flows
Icelandite
Mafic volcaniclastic rocks
Rhyolitic flows
Felsic breccia
VMS lenses
Erosion level

Figure GS-2-3: *Idealized stratigraphic section depicting the footwall and hangingwall to the Flin Flon VMS deposits (modified from Devine et al., 2002; Ames et al., 2002; Devine, 2003; DeWolfe and Gibson, 2004, 2005; Simard, GS-1, this volume).*

The Reservoir member is a green, aphyric to weakly plagioclase- and pyroxene-porphyritic (<15%) fine-grained basalt, and occurs as massive, pillowed and peperite facies. It occurs stratigraphically above the 1920 unit as sills and flows, and locally as sills below the 1920 unit (Figure GS-2-3). Where the 1920 unit is absent, the Reservoir member is in direct contact with the overlying plagioclase-porphyritic Stockwell member. The Reservoir member ranges in total thickness from 92 to 148 m, with individual flows ranging from 5 to 80 m thick.

The Stockwell member is a strongly plagioclase-porphyritic (≥15%) basalt and occurs as massive, pillowed and in situ–brecciated pillowed facies. The Stockwell member occurs north of the Railway Fault on both the west and east limbs of the Hidden syncline, forming a continuous unit around its fold nose (Figure GS-2-2; DeWolfe, 2005). It has a thickness of 57 m on the west limb and 79 m on the east limb (approximate true thickness). In one location in the western fault block on the west limb of the Hidden syncline, the Stockwell member occurs immediately above the 1920 unit. It is more commonly located, however, directly above Reservoir member flows and sills (Figure GS-2-3). The top of the Stockwell member is marked by undifferentiated aphyric basaltic flows of the Hidden formation.

In most places, the upper contact of the Hidden formation is defined by a thinly bedded to laminated mafic tuff. This unit ranges from <1 m to several metres in thickness. The true thickness of this tuff unit is frequently difficult to ascertain, as it is commonly intruded by multiple mafic sills. Along the west side of Louis lake and continuing south to the east side of Phantom Lake (south of the golf course), the mafic tuff is locally strongly epidote-quartz altered and contains sporadic sulphide mineralization (marked by strong iron-staining). The upper part of the mafic tuff unit locally contains beds of rhyolitic lapilli tuff (>20% aphyric rhyolite clasts, 0.2–10 cm in size) and, where this is the case, these rhyolite-bearing breccia beds are included in the Tower member of the Louis formation (*see* description below).

Northwest of Carlisle Lake, the contact between the Hidden and Louis formations is marked by a change from aphyric, very strongly epidote-quartz-altered and silicified, pillowed basaltic flows of the Hidden formation to plagioclase- (15%) and pyroxene (5%)-porphyritic basaltic flows of the Louis formation. At this location, the Louis formation flows display only weak, pervasive epidote-quartz alteration, suggesting that the alteration is synvolcanic and predates deposition of the Louis formation.

Louis formation

The Louis formation is dominated (>85%) by plagioclase (>15%)- and pyroxene (>5%)-porphyritic basaltic flows (Figure GS-2-4a). It includes two mappable members near its base: the Tower member, an aphyric rhyolite unit with associated breccia and mafic tuff (Figures GS-2-4b, -4c, -4d, -4e); and the Icehouse member, a strongly plagioclase-pyroxene-porphyritic basaltic flow (Figures GS-2-5b, -5c, -5d, -5f, -6).

Where the Tower member is not present, the base of the Louis formation is defined by 1) the first occurrence of plagioclase-pyroxene-porphyritic basaltic flows, 2) aphyric basaltic flows followed by plagioclase-pyroxene-porphyritic basaltic flows, 3) aphyric or sparsely feldspar- and quartz-porphyritic rhyolitic flows overlain by plagioclase-pyroxene-porphyritic flows or aphyric then plagioclase-pyroxene-porphyritic basaltic flows (Figure GS-2-6). In all cases, rocks above the contact with the underlying Hidden formation are dominated by plagioclase-pyroxene-porphyritic flows. The top of the Louis formation is not exposed and is therefore represented by the present-day erosion surface (Figure GS-2-3).

Tower member

Distribution

The Tower member rhyolite is aerially restricted, occurring only near the water tower on Sipple hill (Figure GS-2-2); however, a time-stratigraphic equivalent rhyolite occurs in the Schist Lake–Mandy Road area to south (*see* Simard, GS-1, this volume). The Tower member ranges from <1 to 20 m thick (not true thickness), but this thickness is only an estimate due to folding and a crosscutting mafic intrusion.

Lithology

The Tower member consists of massive to in situ–brecciated, aphyric or sparsely feldspar- and quartz-porphyritic rhyolite and volcaniclastic rocks dominated by aphyric rhyolite clasts locally overlain by mafic tuff.

Contact Relationships

The lower contact of the rhyolite is conformable, with in situ–brecciated rhyolite in sharp but irregular contact with the underlying amygdaloidal, aphyric, pillowed basalt of the Hidden formation (Figures GS-2-3, -4b). The upper contact of the rhyolite is sharp and conformable with an overlying mafic tuff (Figure GS-2-4c), which contains beds (5%) with 5 to 20% rhyolite clasts (0.2–20 cm). A similar rhyolite at Burley Lake is conformably overlain by basaltic plagioclase-porphyritic flows (Simard, GS-1, this volume). At Sipple hill and along strike, the upper contact of the Tower member is generally missing due to a fine- to medium-grained mafic intrusion that crosscuts the contact.

Massive facies

The massive, coherent facies of the Tower member rhyolite occurs within the middle of the unit. The rhyolite is aphyric, locally flow banded, strongly silicified and locally sericitized.

In situ–brecciated facies

The in situ–brecciated facies of the Tower member rhyolite occurs locally at the bottom of the unit along the contact with the underlying pillowed basalt of the Hidden formation and along the top of the unit. The in situ breccia is characterized by angular to subrounded fragments of rhyolite, 5 to 25 cm in size, closely packed with only hairline fractures between fragments (jig-saw puzzle fit; Figure GS-2-4d).

Volcaniclastic facies

The volcaniclastic facies of the Tower member locally occurs along the lower contact of the rhyolite. The volcaniclastic facies is crudely bedded and clast supported; bedding is defined by changes in clast size. The volcaniclastic facies contains lapilli- to block-sized fragments of aphyric rhyolite, subrounded to rounded, in a fine-grained (mafic?) tuff matrix (Figure GS-2-4e). The volcaniclastic facies also contains rounded, aphyric basalt clasts (5–10%, <8 cm in size).

Icehouse member

Distribution

The Icehouse member occurs between the water tower on Sipple hill and the northernmost extent of Louis lake (Figure GS-2-2). Near the water tower, it includes two massive flows with a combined thickness of 110 m (not true thickness). Farther south, the member is defined by one massive to pillowed flow, which is 43 m thick and thins to 27 m at its southernmost extent, west of the northern tip of Louis lake.

Lithology

The Icehouse member is massive to pillowed, locally overlain by mafic volcaniclastic rocks. It is coarsely porphyritic and contains 20 to 25% plagioclase phenocrysts, ranging in size from 1 to 5 mm, and 15 to 20% pyroxene phenocrysts, ranging in size from 1 to 8 mm.

Contact Relationships

To the north, the Icehouse member has a lower contact with a mafic intrusion. Its upper contact is marked

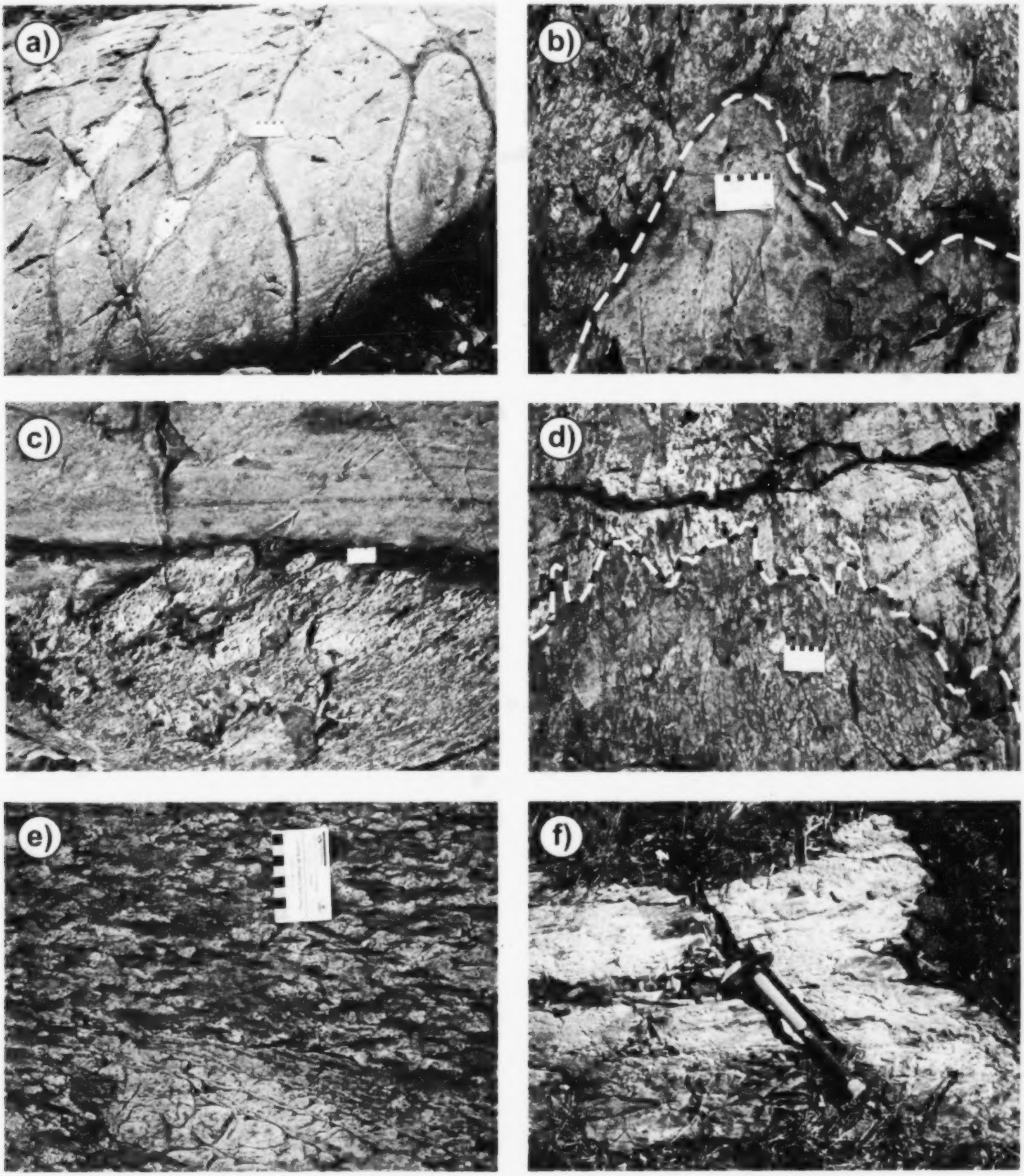

Figure GS-2-4: *Photographs of the Louis formation, Flin Flon area:* ***a)*** *plagioclase-pyroxene-porphyritic pillowed basalt with quartz-epidote-altered mafic tuff between pillows;* ***b)*** *contact (dashed white line) between aphyric pillowed basalt of the Hidden formation (bottom) and in situ–brecciated rhyolite of the Tower member, Louis formation (top);* ***c)*** *in situ–brecciated rhyolite of the Tower member in contact with overlying, finely laminated mafic tuff;* ***d)*** *internal contact (dashed white line) within the Tower rhyolite between heterolithic (rhyolite-dominated) volcaniclastic bed (bottom) and in situ–brecciated coherent rhyolite (top);* ***e)*** *heterolithic (rhyolite-dominated) volcaniclastic bed within the Tower member;* ***f)*** *strongly quartz-epidote-altered and iron-stained mafic (?) tuff, which locally marks the contact between the Hidden and Louis formations.*

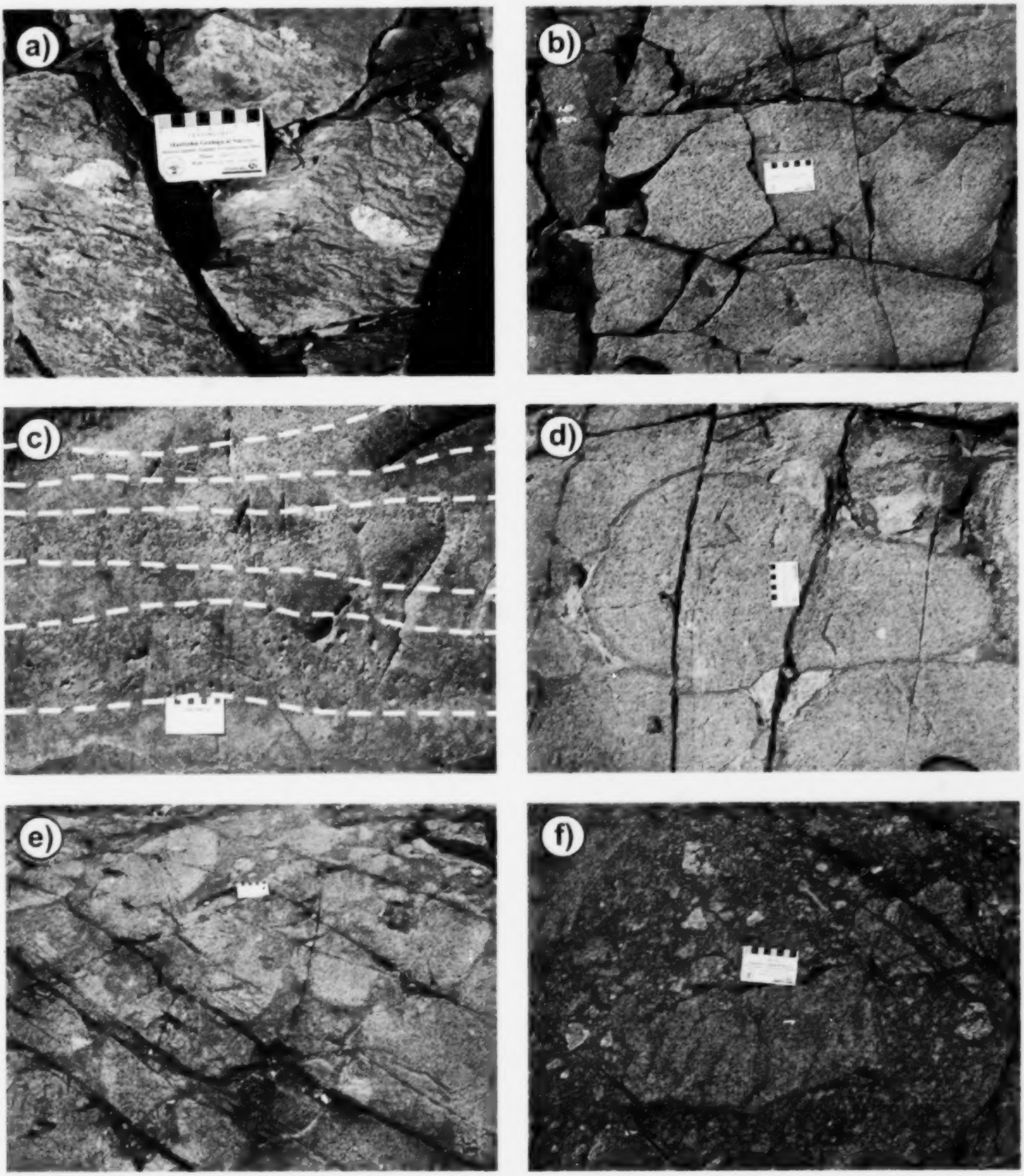

Figure GS-2-5: Photographs of the Louis formation, Flin Flon area: ***a)*** *aphyric rhyolite clasts within a mafic tuff of the Tower member, denoting the contact between the Hidden and Louis formations;* ***b)*** *columnar-jointed, coarsely plagioclase-pyroxene-porphyritic basalt of the Icehouse member;* ***c)*** *fine-grained flow top with bands of amygdules (dashed white lines) parallel to the flow top;* ***d)*** *pillowed, coarsely plagioclase-pyroxene-porphyritic basalt with quartz-epidote-altered mafic tuff between pillows, Icehouse member;* ***e)*** *pillow breccia overlying pillowed flow shown in part (d);* ***f)*** *heterolithic volcaniclastic unit overlying pillow breccia shown in (e).*

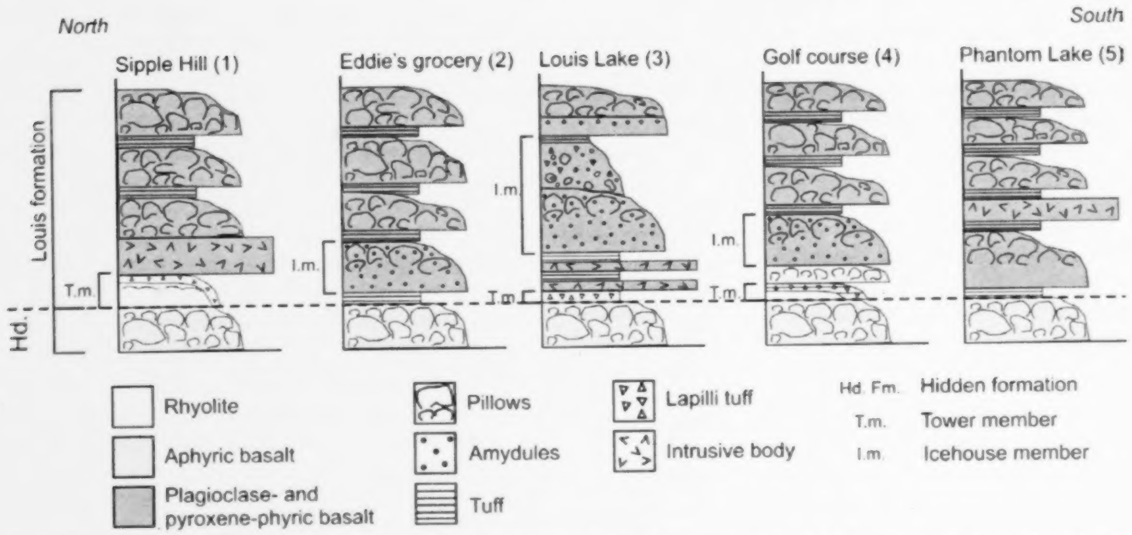

Figure GS-2-6: *Idealized stratigraphic sections showing the contact between the Hidden and Louis formations in five different locations (see Figure GS-2-2), moving from north to south through map area.*

by a finely laminated mafic tuff, or a massive-bedded mafic lapilli tuff that is 1 to 4 m thick, or both. To the south, the Icehouse member has a sharp and conformable contact with an underlying, finely laminated, strongly silicified and iron-stained, mafic tuff to lapilli tuff containing clasts of rhyolite (>20% aphyric rhyolite clasts, 0.2–10 cm in size). The rhyolite-clast-bearing mafic volcaniclastic rock marks the bottom of the Tower member of the Louis formation (Figures GS-2-4f, -5a, -6). A 20 m thick heterolithic volcaniclastic unit marks the upper contact of the Icehouse member to the south (Figures GS-2-5e, -5f).

Massive facies

The massive facies of the basaltic flows of the Icehouse member is coarsely plagioclase (25–30%, 1–3 mm) and pyroxene (20%, 1–7 mm) porphyritic and commonly columnar jointed (Figure GS-2-5b). Where in contact with pillows, the massive facies grades into the pillowed facies over a distance of 1 to 2 m. Near the flow-top, the massive facies increases in quartz amygdule content from 5 to 30% (<1–5 cm). At one locality, the massive flow is finer grained over the upper 5 m and, in the uppermost metre, the flow contains bands of amygdules (20–30%, <2 cm) that are 5 to 10 cm wide and oriented parallel to the flow top (Figure GS-2-5c).

Pillowed facies

Pillows are 0.2 to 1 m wide with thin (≤2 cm) selvages, and contain 5 to 10% quartz amygdules (<1 cm). Finely laminated epidote-quartz-altered mafic tuff commonly occurs between the pillows (Figure GS-2-5d). The upper margin of the pillowed flow of the Icehouse member is irregular and broken, with a gradation over a distance of 1 m from intact pillowed flow to pillow breccia to an overlying volcaniclastic facies (Figure GS-2-5e; *see* description below).

Volcaniclastic facies

Overlying the pillowed facies is a 20 m thick, normally graded, heterolithic volcaniclastic unit. The lower 5 m is clast supported, with 20% large blocks (6.4–50 cm) of plagioclase- and pyroxene-porphyritic, quartz amygdaloidal basalt and 5 to 10% aphyric rhyolite blocks (angular to subrounded; Figure GS-2-5f). Overall, the unit contains 50% lapilli-sized, rounded, aphyric to plagioclase- and pyroxene-porphyritic basalt clasts. The matrix is a reddish brown colour and rich in plagioclase (20–25%) and pyroxene (15%) crystals. The next 3 to 5 m marks a transition from clast supported to matrix supported. In this interval, there are only 5% large plagioclase- and pyroxene-porphyritic pillow fragments (>10 cm), 3 to 5% aphyric rhyolite clasts (rounded and ≤15 cm), and 10 to 20% lapilli-sized, aphyric to plagioclase- and pyroxene-porphyritic basalt fragments. The upper 10 m of the unit is matrix supported, consisting mainly of tuff with 30% rounded, lapilli-sized basalt clasts and 5 to 10% subrounded, aphyric rhyolite clasts.

Undivided basalt flows

Distribution

Overlying the Icehouse member of the Louis formation are undivided basaltic flows that account for

>90% of the observed flows of the Louis formation. The undivided flows have a minimum total thickness of 200 m and a maximum of 800 m, but estimating thickness is complicated by thrusting and folding. Individual flows range in thickness from approximately 10 to 50 m.

Lithology

The undivided flows are massive to pillowed and commonly separated by mafic volcaniclastic units. These flows are porphyritic, containing >15% plagioclase phenocrysts that range in size from 1 to 3 mm and >5% pyroxene phenocrysts that range in size from 1 to 4 mm.

Contact Relationships

The undivided flows of the Louis formation have a conformable lower contact, marked by a mafic volcaniclastic unit (1–20 m thick) with underlying flows of the Icehouse member. The top of the undivided flows is not exposed and is therefore represented by the present-day erosion surface (Figure GS-2-3).

Massive facies

The massive facies of the undivided flows is plagioclase (>15%) and pyroxene (>5%) porphyritic, brown (weathered) or dark grey (fresh) in colour, and accounts for less than half (~30%) of the flows, most of which are pillowed. The massive facies, which typically occurs as the massive portion of multifacies flows, normally displays gradational contacts over 1 to 2 m with the pillowed facies.

Pillowed facies

The pillowed facies of the undivided flows is plagioclase (>15%) and pyroxene (>5%) porphyritic, brown (weathered) or dark grey (fresh) in colour, and contains amygdaloidal pillows that range in size from 0.5 to 2.5 m. The amygdules are quartz filled, range in size from 0.1 to 2.0 cm, are rarely concentrated towards the top margin of the pillow, and are commonly distributed throughout the pillow. Pillow selvages have an average width of 1 cm and are a dark brown to red. Undivided pillowed flows of the Louis formation commonly contain epidote-quartz-altered mafic tuff between the pillows (Figure GS-2-4a).

Volcaniclastic facies

Within the Louis formation, pillowed basalt flows are often separated by mafic volcaniclastic units ranging from <1 to 5 m in thickness. The volcaniclastic units range from clast-supported, massive lapilli tuff beds to finely laminated mafic tuff beds. Lapilli tuff beds consist of 70% plagioclase-pyroxene-porphyritic, amygdaloidal basalt clasts that are rounded to subangular in form and range in size from 0.2 to 6 cm, with an average clast size of 2 cm. They also contain 10% aphanitic basalt clasts (0.2 to 3 cm and subrounded to subangular) and have a grey to brown tuff matrix.

Interpretation

The basaltic to andesitic flows and sills of the Hidden formation are interpreted to represent products of a large shield volcano with a synvolcanic graben and volcanic vent located on the northwest limb of the Hidden syncline. The graben and volcanic vent structure correspond spatially to the location of the 1920 unit (DeWolfe and Gibson, 2005).

Supporting evidence for a graben and a vent-proximal environment on the west limb of the Hidden syncline, where the 1920 unit occurs, includes 1) the presence of volcaniclastic units overlying the 1920 unit and separating multiple flows within the Stockwell member that do not extend to the Stockwell member on the west limb, indicating deposition within a topographic depression; 2) large (up to 20 m by 10 m) domains of massive facies, surrounded by pillows in flows of the Reservoir and Stockwell members, that are interpreted to be large lava tubes emanating from a proximal magma source; and 3) an abundance of synvolcanic basaltic dikes and sills within the 1920 unit and Reservoir and Stockwell members in this area. On the east limb of the fold, flows of the Reservoir and Stockwell members are thinner and characterized by abundant sills, not dikes, indicating emplacement farther from a volcanic vent. The top of the Hidden formation is commonly marked by an extensive mafic tuff unit, indicating a significant hiatus in volcanism between emplacement of the Hidden and Louis formations (Ames et al., 2002, 2003).

Locally, the base of the Louis formation is marked by rhyolite of the Tower member, which, along with aphyric and or plagioclase-pyroxene-porphyritic flows, marks the onset of a second episode of mafic-dominated volcanism following the hiatus at the top of the Hidden formation. The rhyolite is interpreted to have been emplaced as a flow or dome (containing autoclastic breccia) on the seafloor. Rhyolite fragments within the upper part of the mafic tuff are interpreted to have been derived, possibly through mass wasting, from the Tower member rhyolite. Overlying the rhyolite are two very thick, massive, strongly plagioclase-pyroxene-porphyritic flows of the Icehouse member (Figure GS-2-6). These flows do not contain flow-top breccia, but instead fine upwards and, over their upper 1 to 5 m, become more intensely quartz amygdaloidal where they are conformably overlain by a finely laminated, strongly epidote-quartz-altered mafic tuff to lapilli tuff. The absence of peperite along the upper contact of the flows suggests that the tuff was deposited on top of the flows, which were emplaced on the seafloor.

The thick Icehouse flows are interpreted to be ponded or represent lava lakes on the seafloor. Farther south, where the Icehouse member thins and is represented by one flow, it grades into a pillowed facies (Louis lake section, Figure GS-2-6). Where the heterolithic volcaniclastic facies overlies the thick Icehouse member flow, the former is interpreted to have been emplaced within a small (<50 m) synvolcanic graben that also constrained the underlying ponded flows. Reactivation of faults bounding the massive Icehouse flows is interpreted to have exposed the underlying rhyolite (Tower member) and triggered mass flows, which resulted in a localized volcaniclastic deposit (facies), comprising basaltic and rhyolitic detritus, that was deposited in a fault-controlled basin.

The combination of the thick rhyolitic (Tower member) and basaltic (Icehouse member) flows, a localized basin defined by the volcaniclastic facies, and the high proportion of intrusions implies proximity to a volcanic vent and one or more synvolcanic subsidence structures that were active during the onset of Louis formation volcanism. Moving laterally away from the Tower and Icehouse members, which correspond to a vent-proximal environment, the undivided plagioclase-pyroxene-porphyritic flows of the Louis formation begin to dominate. These basaltic flows, which are thinner than those of the Icehouse member, represent a more distal volcanic environment. The flows of the Louis formation are interpreted to represent resurgence in basaltic volcanism and associated subsidence, which continued the growth of a shield volcano. The location of the volcanic vent within the Louis formation differs from that in the underlying Hidden formation, and is in the area between Sipple hill and Louis lake.

Economic considerations

The contact between the Hidden and Louis formations marks an important hiatus in volcanism, and the intense epidote-quartz alteration found along this contact, whether in pillowed, aphyric basaltic flows at the top of the Hidden formation or mafic tuff that locally marks the top of the Hidden formation, indicates the existence of hydrothermal alteration during their emplacement (Ames et al., 2002, 2003). Consequently, this contact may be prospective along strike at depth.

The localized volcaniclastic rocks that overlie the Icehouse member of the Louis formation between Sipple hill and the northern extent of Louis lake (Figures GS-2-2, -6) represent an area of synvolcanic subsidence and a hiatus in volcanism with active hydrothermal activity. Similarly, the volcaniclastic units that overlie the 1920 unit and separate numerous flows within the Stockwell member represent hiatuses in volcanism, occur within a topographic depression in a vent-proximal environment and correspond to rocks that have experienced hydrothermal activity. Similar structures are interpreted to host the Flin Flon VMS orebodies in the underlying Flin Flon formation and, as such, these features in the Hidden and Louis formations may represent domains within the hangingwall that have prospectivity for VMS mineralization along strike at depth.

Acknowledgments

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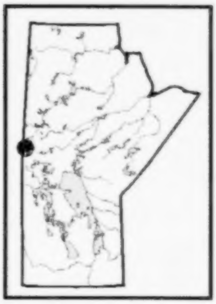
GS-3 Wonderland gabbro: U-Pb age and geological implications, Manitoba (NTS 63K12NE)

by A.H. Bailes and P. Theyer[1]



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Summary

The Wonderland gabbro is one of several gabbroic bodies in the Bear Lake Block of the Flin Flon Belt that are spatially associated with small Ni- and PGE-rich sulphide zones, including the McBratney Ni-PGE-Au occurrence. A genetic association between the Ni-PGE-Au mineralization and these intrusions is difficult to establish with certainty, but elevated (>200 ppb) grab sample Pt-Pd concentrations from the Wonderland gabbro point to a possible primary association with this mineralization. The 1839.9 ±3.9 Ma age of the intrusion indicates that it postdates juvenile oceanic arc volcanism of the host Bear Lake basalts by at least 45 million years. The Wonderland gabbro is, within error, the same age as the 1847 ±6 Ma ultramafic intrusion that hosts the magmatogenic PGE-rich Namew Lake Cu-Ni sulphide deposit. The association of this suite of syn- to post-Missi intrusions with Ni and PGE mineralization raises the possibility that an intrusive event of this age could be a significant and only partly explored metallogenic episode in the Flin Flon Belt.

Introduction

The volcanic rocks of the Flin Flon Belt are intruded by numerous generations of gabbroic intrusions. Most of them belong to three suites. The first suite comprises the oldest and most abundant intrusions, which are syn-volcanic feeders to 1.91 to1.88 Ga juvenile oceanic arc volcanism. The second suite includes mafic phases of 'successor arc', 1.87 to1.845 Ga calcalkaline granitic plutons. The third suite is the least abundant and contains post-1.845 Ga intrusions that locally intrude ca. 1.84 Ga fluvial, alluvial and turbiditic sedimentary rocks of the Missi and Burntwood groups. Nickel-bearing sulphide mineralization has been reported from some of this third suite of intrusions (e.g., Rice Island on Wekusko Lake). This suite may also include the 1847 ±6 Ma (Cumming and Krstic, 1991) ultramafic intrusion, which contains the magmatogenic Cu-Ni-Co-PGE-rich Namew Lake massive sulphide deposit.

Geological setting

The Flin Flon Belt, which belongs within the juvenile (internal) zone of the Trans-Hudson Orogen (Figure GS-3-1), is a collision zone formed during the 2.0 to 1.8 Ga amalgamation of several Archean microcontinents into a supercontinent, Laurentia (Hoffman, 1988). This collage of 1.92 to 1.88 Ga tectonostratigraphic assemblages was assembled during the 1.88 to 1.87 Ga intra-oceanic accretion and subsequent 1.84 to 1.78 Ga terminal collision of the bounding Archean cratons (Lucas et al., 1996). It includes juvenile arc (~68%), juvenile ocean floor (~20%), and minor (~12%) oceanic plateau, ocean island basalt, 'evolved' plutonic arc and undivided rocks (Syme and Bailes, 1993; Stern et al., 1995a, b; Syme et al., 1999). Oceanic arc assemblages include tholeiite, calcalkaline and rare shoshonite and boninite suites (Stern et al., 1995a) almost identical to those forming in modern intra-oceanic arcs (e.g., Gill, 1981).

The Wonderland Gabbro belongs to a cluster of gabbro, diorite and quartz diorite plugs and stocks that cut the Bear Lake basaltic andesite flows east of Big Island Lake (known unofficially as Manistikwan Lake). They occur in the Bear Lake Block, which is one of several fault-bounded blocks of pre-1.88 Ga juvenile arc volcanic rocks in the central Flin Flon Belt (Figure GS-3-2). Each of these blocks displays a unique stratigraphy and, in some cases, a distinct geochemical character (Bailes and Syme, 1989). Similar gabbroic intrusions are found in other fault-bounded blocks (Bailes and Syme, 1989) suggesting that this suite of mafic intrusions may be younger than 1.87 Ga and postdate the 1.88 to 1.87 Ga intra-oceanic accretion event. No intrusions comparable to the Wonderland gabbro are present in the ca. 1.845 Ga Missi Group fluvial-alluvial sedimentary rocks prompting Bailes and Syme (1989) to include them in their "Pre-Missi Intrusive Rocks".

Wonderland gabbro

The elongate north-trending 0.5 by 1.5 km Wonderland gabbro plug is crudely zoned from a light brown weathering gabbro in the east to a buff brown to reddish brown weathering quartz diorite in the west (Bailes and Syme, 1989; Theyer and Heine, 2002). The gabbro is interpreted to be younger than the east-younging Bear Lake flows because its zonation indicates a west top that is opposite to that of the host flows. The Wonderland gabbro is an inhomogeneous body comprising a variety

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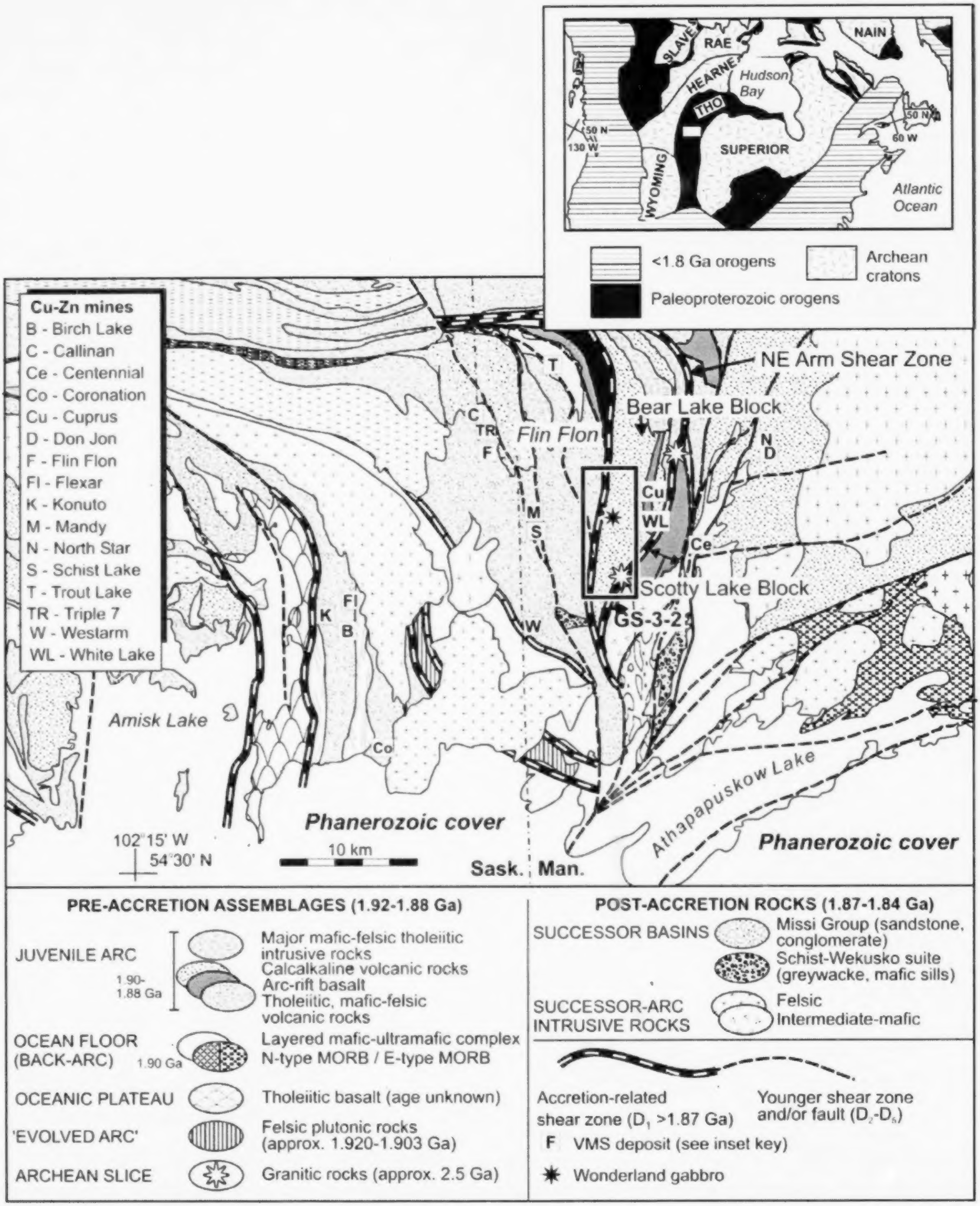
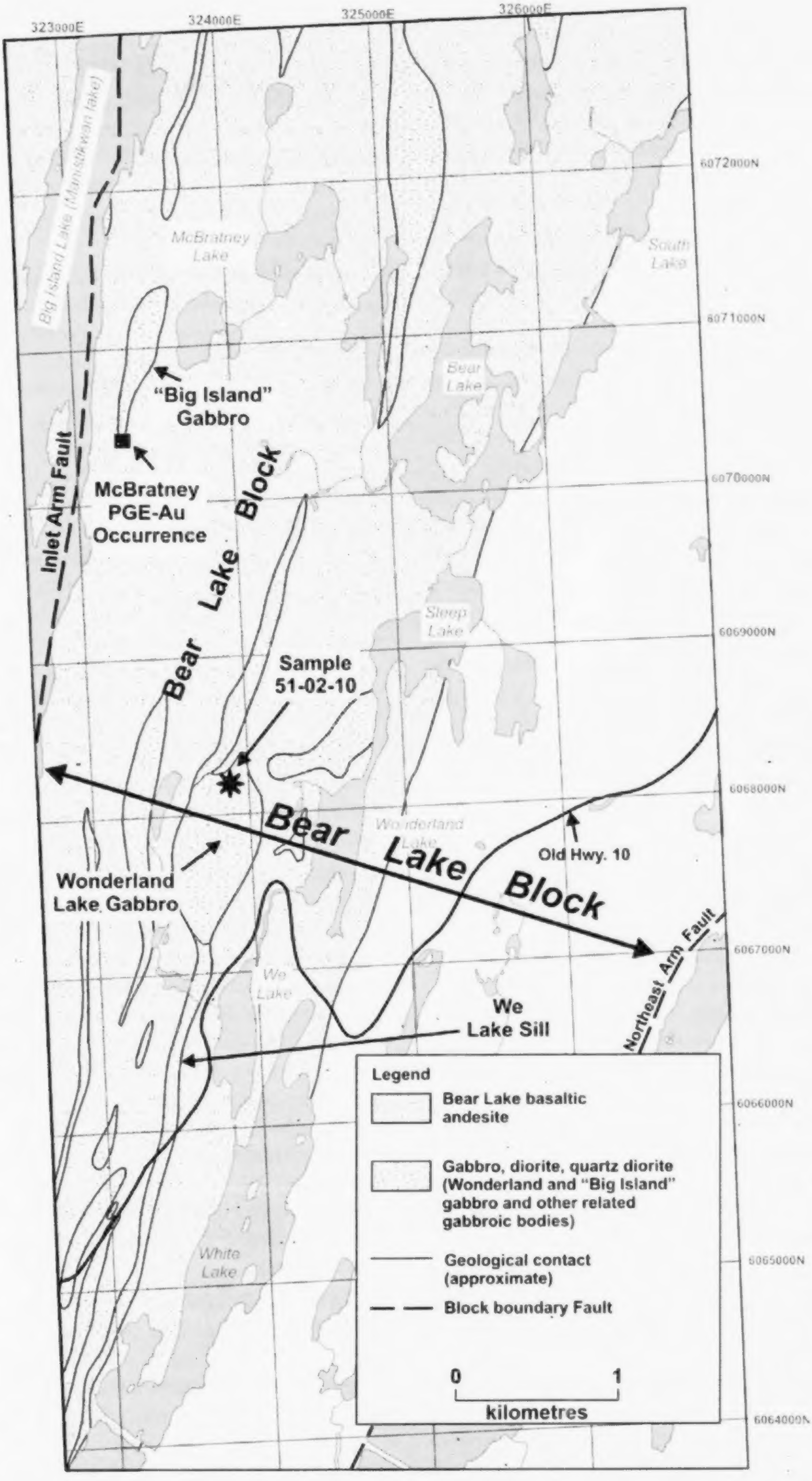

RAE
NAIN
SLAVE
HEARNE
Hudson Bay
THO
SUPERIOR
WYOMING
50 N
130 W
50 N
60 W
Atlantic Ocean
<1.8 Ga orogens
Archean cratons
Paleoproterozoic orogens
Cu-Zn mines
B - Birch Lake
C - Callinan
Ce - Centennial
Co - Coronation
Cu - Cuprus
D - Don Jon
F - Flin Flon
Fl - Flexar
K - Konuto
M - Mandy
N - North Star
S - Schist Lake
T - Trout Lake
TR - Triple 7
W - Westarm
WL - White Lake
NE Arm Shear Zone
Bear Lake Block
Flin Flon
Scotty Lake Block
GS-3-2
Amisk Lake
Athapapuskow Lake
Phanerozoic cover
Phanerozoic cover
102°15' W
54°30' N
10 km
Sask.
Man.
PRE-ACCRETION ASSEMBLAGES (1.92-1.88 Ga)
JUVENILE ARC
1.90-1.88 Ga
Major mafic-felsic tholeiitic intrusive rocks
Calcalkaline volcanic rocks
Arc-rift basalt
Tholeiitic, mafic-felsic volcanic rocks
OCEAN FLOOR (BACK-ARC)
1.90 Ga
Layered mafic-ultramafic complex
N-type MORB / E-type MORB
OCEANIC PLATEAU
Tholeiitic basalt (age unknown)
'EVOLVED ARC'
Felsic plutonic rocks (approx. 1.920-1.903 Ga)
ARCHEAN SLICE
Granitic rocks (approx. 2.5 Ga)
POST-ACCRETION ROCKS (1.87-1.84 Ga)
SUCCESSOR BASINS
Missi Group (sandstone, conglomerate)
Schist-Wekusko suite (greywacke, mafic sills)
SUCCESSOR-ARC INTRUSIVE ROCKS
Felsic
Intermediate-mafic
Accretion-related shear zone (D1 >1.87 Ga)
Younger shear zone and/or fault (D2-D5)
F VMS deposit (see inset key)
Wonderland gabbro

***Figure GS-3-1**: Geology of the central portion of the Flin Flon Belt, showing the location of the Wonderland gabbro in the Bear Lake Block (after Syme et al., 1996). Box indicates area covered by Figure GS-3-2. Inset map shows the location of the Flin Flon Belt within the Trans-Hudson Orogen.*


323000E
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6067000N
6066000N
6065000N
6064000N
Big Island Lake (Manistikwan lake)
McBratney Lake
South Lake
Bear Lake
Sleep Lake
Wonderland Lake
We Lake
White Lake
"Big Island" Gabbro
McBratney PGE-Au Occurrence
Inlet Arm Fault
Bear Lake Block
Sample 51-02-10
Bear Lake Block
Old Hwy. 10
Wonderland Lake Gabbro
Northeast Arm Fault
We Lake Sill
Legend
Bear Lake basaltic andesite
Gabbro, diorite, quartz diorite (Wonderland and "Big Island" gabbro and other related gabbroic bodies)
Geological contact (approximate)
Block boundary Fault
0
1
kilometres

***Figure GS-3-2:** Location of the Wonderland Gabbro, 'Big Island gabbro' and other similar gabbro, diorite and quartz diorite intrusions (after Bailes and Syme, 1989) in the Bear Lake Block. The location of the geochronology sample site is indicated by the asterisk. Place names in parentheses are unofficial.*

of rock types, including granite, diorite and gabbro (Theyer and Heine, 2002). Randomly located areas of hybrid granitic to dioritic rocks, characterized by melanocratic inclusions, schlieren and bands contained in a more felsic matrix are common. These features were interpreted by Theyer and Heine (2002) to result from magma mixing. Olivo et al. (2002) came to the same conclusion based on similar observations in the 'Big Island gabbro'.

Discrete, sharply defined sulphide-bearing zones, up to several metres in size and containing up to 10% coarse-grained, recrystallized pyrite, occur in the central part of the Wonderland Gabbro. The sulphide-bearing zones are likely magmatogenic, as their composition and the amount and type of alteration are comparable to those of the non-mineralized host gabbro. The sulphide-bearing gabbro is recognized by its distinctly finer grain size and its red and brown limonitic oxidation on weathered surfaces.

The sulphide zones, both within and spatially associated with this suite of gabbro intrusions, have been known for some time. Interest in them was sparked in 1991, when Hudson Bay Exploration and Development Co. Ltd. drilled a sulphide zone spatially associated with the 'Big Island gabbro' (Figure GS-3-2). In this drillhole, they intersected 16.8 m assaying 8.92 g/t Pd, 1.8 g/t Pt, 1.1% Cu and 0.6% Ni. Follow-up work by Fort Knox Gold Resources Inc. in 2000 and 2001 (Assessment File 73880, Manitoba Science, Technology, Energy and Mines, Winnipeg) further defined the extent of this mineralized zone, commonly known as the McBratney Lake Ni-PGE-Au occurrence. Channel sampling intersected high-grade zones of 5.0% Cu, 4.7% Ni, 9.5 g/t and 30 g/t Pd over 1.75 m, and 6.1% Cu, 4.2% Ni, 9.4 g/t and 31.2 g/t Pd over 1.35 m.

As part of their exploration program, Fort Knox Gold Resources Inc. prospected other gabbroic bodies within this suite of intrusions. They did this on the premise that a genetic affiliation between the PGE-Au mineralization and the gabbro intrusions might exist. Samples from the Wonderland gabbro were of great interest, as 50% of the 18 samples collected displayed elevated (>200 ppb) Pt-Pd, with 3 samples returning over 500 ppb Pt-Pd (A.F. 73880). Although not conclusive, this does support a potential genetic link between the intrusions and the PGE mineralization.

Because of the potential economic importance of this suite of gabbro intrusions (Theyer, 2001; Theyer and Heine, 2002), the Manitoba Geological Survey decided to date this intrusion and, by inference, the associated Ni-PGE-Au mineralization. The interpretation of the age of the Ni-PGE-Au mineralization is, however, complicated by the fact that the mineralization at the McBratney Lake occurrence appears to be hydrothermal in origin and related to carbonate-chlorite vein and replacement zones (Olivo et al., 2002; Olivo and Theyer, 2004).

Sampling and geochronology

The geochronology sample (51-02-10; 6068276N, 323925E, UTM zone 14, NAD 83) is from a pegmatitic pod within the mixed, transitional contact between the gabbro and quartz diorite zones of the Wonderland gabbro. The pegmatitic pods in this zone are characterized by coarse, 1 to 3 cm lath-shaped pyroxenes (replaced by amphibole) in a coarse-grained matrix composed of plagioclase and quartz.

Approximately 30 kg of the pegmatitic Wonderland gabbro was processed for U-Pb dating at the University of Alberta Radiogenic Isotope Facility in Edmonton. The sample was milled using standard crushing (jaw crusher followed by Sico® disk mill) techniques. Isolation of zircon was accomplished by Wilfley Table, heavy liquid and magnetic mineral separation techniques. Individual zircon crystals were selected from mineral concentrates for U-Pb analysis based on clarity and grain morphology using a binocular microscope. Zircon crystals with fractures, alteration or inclusions were avoided where possible during the selection process. Selected mineral grains or fractions were dissolved in acids, and purified aliquots of U and Pb were obtained using anion exchange chromatography. The isotopic compositions of U and Pb were determined on a solid-source thermal ionization mass spectrometer. All ages are calculated using the following decay constants: 1.55125×10^{-10} per year for ^{238}U and 9.8485×10^{-10} per year for ^{235}U. The uncertainties associated with all age calculations reported in the text are quoted at two sigma.

Abundant apatite, a small amount of colourless zircon, plus trace euhedral pyrite and molybdenite were recovered from this sample. The zircon grains typically consist of fragments and shards with a few prismatic sections present. Most of the crystals were recovered in quite magnetic Frantz splits. Seven zircon fractions were selected from this sample, but fraction 1 failed. The U-Pb results for six zircon fractions (consisting of between 6 and 28 fragments) are presented in Table GS-3-1 and on a concordia diagram in Figure GS-3-3. All six fractions display a similar chemical composition with moderate to high U (461–1496 ppm) and Th (414–1173 ppm) contents and relatively high Th/U (0.65–0.90). These high Th/U ratios are typical for primary zircon crystallizing from a mafic magma.

The zircon analyses are generally discordant (6.8–32.2%) with ^{207}Pb/^{206}Pb ages that vary between 1723 and1862 Ma. The analyses are seemingly collinear, but a regression calculation indicates there is slight scatter and using all six analyses yields an age with large uncertainties. A regression calculation using the three most precise analyses (3, 4, 7) yields an upper intercept age of 1839.9 ±3.9 Ma (mean standard weighted deviation (MSWD) = 0.18) and a lower intercept age of 406 ±20 Ma.

Table GS-3-1: U-Pb Zircon Results, Wonderland Gabbro, Sample 51-02-10.

Description	Weight (µg)	U (ppm)	Th (ppm)	Pb (ppm)	Th/U	TCPb (pg)	^{206}Pb/^{204}Pb	^{206}Pb/^{238}U	^{207}Pb/^{235}U	^{207}Pb/^{206}Pb	^{206}Pb/^{238}U	^{207}Pb/^{235}U	^{207}Pb/^{206}Pb	% Dis
2z: sl pink elongated striated (7)	8.5	626	493	228	0.79	13	7718	0.331209 ±32	4.9007 ±49	0.11389 ±4	1751.0 ±1.6	1802.4 ±0.9	1862.3 ±0.6	6.8
3z: col elongate striated shards (11)	21.9	461	414	167	0.09	85	2230	0.29855 ±40	4.5677 ±65	0.11096 ±6	1684.1 ±2.0	1743.4 ±1.2	1815.2 ±1.0	8.2
4z: lt pink elongate striated shards Fe staining (14)	27.9	1246	940	388	0.75	475	1201	0.25862 ±36	3.8698 ±60	010852 ±8	1482.8 ±1.9	1607.4 ±1.3	1774.7 ±1.3	18.4
5z: col elongate euh frags (6)	606	1028	771	305	0.75	186	550	0.23408 ±35	3.4694 ±67	0.10749 ±16	1355.9 ±1.8	1520.3 ±1.6	1757.3 ±2.8	25.3
6z:col elongate striated frags (28)	39.1	1496	1173	372	0.78	259	2953	0.20758 ±28	3.0192 ±42	0.01549 ±4	1215.9 ±1.5	1412.5 ±1.1	1722.8 ±0.6	32.2
7z: col elongate euh to subhed frags	6.1	1169	761	343	0.65	49	2346	0.25468 ±33	3.7971 ±53	0.10826 ±5	1461.0 ±1.7	1592.1 ±1.1	1770.3 ±0.8	19.5

All errors reported to 1 s

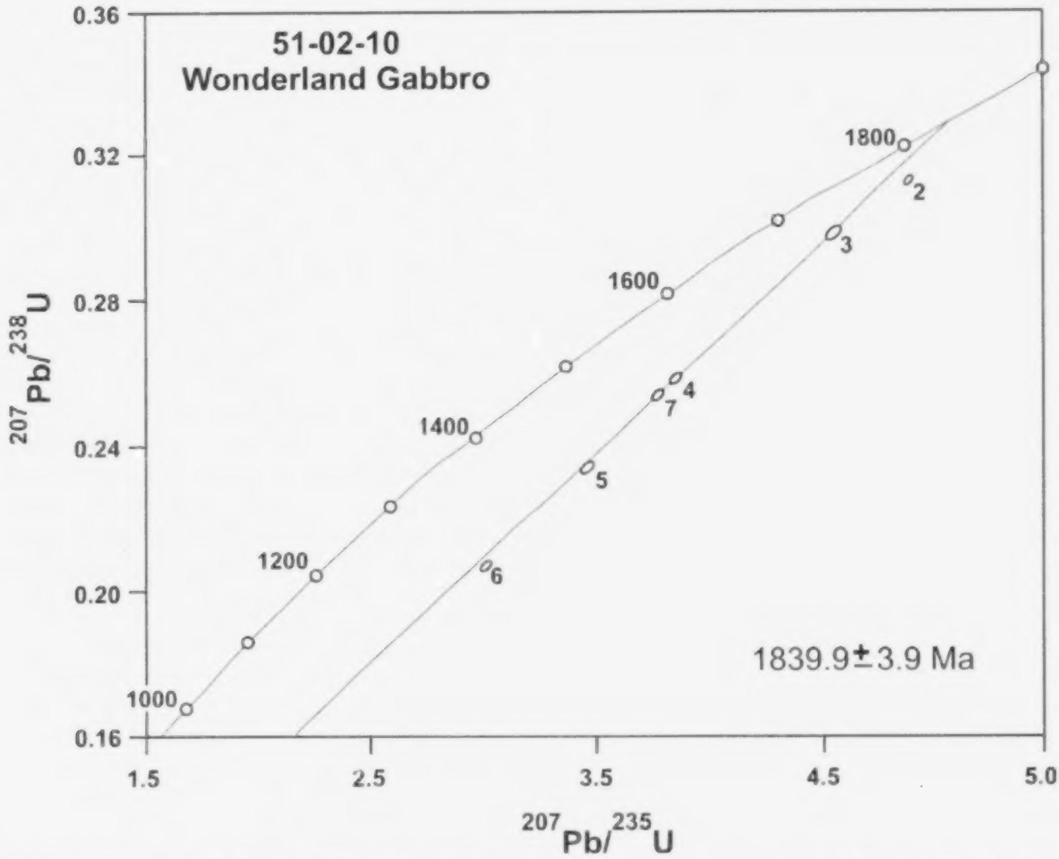

***Figure GS-3-3:** Concordia diagram of U-Pb zircon isotopic analyses from the quartz diorite pegmatite phase of the Wonderland gabbro (sample 51-02-10). Analytical uncertainty is 1σ standard error.*

Implications and economic considerations

The new U-Pb zircon age from the Wonderland gabbro is interpreted to represent the age of crystallization of the intrusion. The age indicates that the Wonderland gabbro postdates the 1.92 to 1.88 Ga juvenile arc volcanism, the 1.87 to 1.845 Ga 'successor arc' magmatism and deposition of the ca. 1.845 Ga Missi and Burntwood sedimentary rocks. The age is also, within error, comparable to that of the 1847 ±6 Ma ultramafic intrusion that hosts the Namew Lake magmatogenic Ni-Cu-Co and PGE-rich sulphide deposit. Although very speculative at this point, the Ni and PGE association of this suite of syn- to post-Missi intrusions raises the possibility they may be part of a significant metallogenic event that has yet to be adequately explored.

Other intrusions of this age include the 'Boundary intrusions' in the vicinity of the Flin Flon Cu-Zn sulphide mine at Flin Flon and the Chisel Lake gabbro near the Chisel Lake Zn-Cu orebody at Snow Lake. The age of the Chisel Lake gabbro is inferred from its crosscutting relationship with isoclinal folds that are interpreted to be the same age as similar folds affecting ca.1.84 Ga Burntwood greywacke turbidite units. A sample of a pegmatitic quartz diorite pod from the Chisel Lake gabbro intrusion has been submitted for U-Pb zircon dating to test this assumption. The extent of the post-1.84 Ga mafic intrusive event is difficult to assess because of its similarity to the ubiquitous 1.92 to 1.88 Ga synvolcanic gabbroic intrusions of the Flin Flon Belt. Given the potential of this mafic intrusive event for hosting Ni and PGE mineralizations, identifying these intrusions and documenting their distribution is important for mineral exploration in the belt.

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GS-4 Metallogenic and metamorphic study of selected deposits from the Snow Lake area and the southern flank of the Kisseynew Domain, Manitoba (NTS 63K16 and 63N2)

by S. Gagné[1], C.J. Beaumont-Smith, A.E. Williams-Jones[1]
and A. Hynes[1]

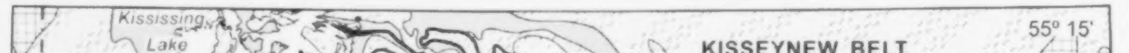
Gagné, S., Beaumont-Smith, C.J., Williams-Jones, A.E. and Hynes, A. 2006: Metallogenic and metamorphic study of selected deposits from the Snow Lake area and the southern flank of the Kisseynew Domain, Manitoba (NTS 63K16 and 63N2); *in* Report of Activities 2006, Manitoba Science, Technology, Energy and Mines, Manitoba Geological Survey, p. 42–48.

Summary

During the 2006 field season, four gold-bearing mineral deposits (Chisel North, Squall Lake, Nokomis Lake and Puffy Lake) were investigated in the Snow Lake greenstone belt and overlying Kisseynew Domain margin. Work carried out at each site included detailed mapping of surface outcrops and trenches, underground mapping, sampling of ore and hostrocks, and relogging and sampling of drill core. The purpose of this field campaign was to collect a set of representative samples from each deposit for detailed textural and chemical analysis, as well as to gain a good understanding of the geological context of the mineralization.

Introduction

This project, which is supported by the Manitoba Geological Survey and the Geological Survey of Canada, aims to investigate the effects of metamorphism on sulphide-gold mineralization. It is part of a larger scope regional gold metallogenic study of the Snow Lake greenstone belt. The 2006 field season permitted the continuation of the project started in 2005 and completion of the sample collection. The sulphide-gold mineralization of the various deposits (Chisel North mine, Squall Lake, Puffy Lake mine and Nokomis Lake; Figure GS-4-1) is hosted by rocks displaying a spectrum of metamorphic conditions from lower to upper amphibolite facies. Each deposit will be studied in a two-fold manner. First, a comparison study will examine the variation in chemistry and mineralogy between the unaltered hostrock, the altered wallrock and the ore to better understand the nature of the mineralization. The conditions and timing of peak metamorphism will be established as accurately as possible for each location. The role of metamorphism in the evolution of the mineralization to its current state


Kississing Lake
KISSEYNEW BELT SOUTH FLANK
KISSEYNEW BELT CORE ZONE
55° 15'
③
④
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File
Snow Lake
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①
Wekusko L
F
Flin Flon
0
20 km
PHANEROZOIC COVER
Successor arc pluton, basin deposits
Late plutons
Missi Group
Burntwood Group
Early plutons and gneiss
Successor-arc plutons
Layered mafic sills
Early plutons, mixed gneiss
Major fault
Early juvenile assemblages
Arc volcanic rocks
Arc-rift basalt
Ocean-floor basalt
③
Gold deposits
99° 15'

Figure GS-4-1: *Generalized geology of the Snow Lake area, showing the location of the selected gold deposits: 1) Chisel North mine, 2) Squall Lake, 3) Nokomis Lake, and 4) Puffy Lake mine.*

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will also be investigated in detail. The results from all the deposits studied will be synthesized to enable a better understanding of the possible effects of increasing P-T conditions on the evolution of sulphide-gold mineralization.

Chisel North mine

The Chisel North mine, owned by Hudbay Minerals Inc., is located about 12 km south of the community of Snow Lake. In 1987, deep step-out exploratory drilling intersected sulphide lenses occurring near the same stratigraphic level as the main Chisel mine orebody but 300 m down plunge. Mining started in 2000. Chisel North is a proximal volcanogenic massive sulphide (VMS) deposit (Galley et al., 1993) with sulphide mineralization occurring mainly as semimassive to massive sphalerite-pyrite. The hangingwall of the deposit, which is enriched in Au, Ag, Cu and Pb, is of interest to this study.

Previous work

The area around Chisel North has been the site of regional mapping by the Manitoba Geological Survey (MGS; Bailes et al., 1996). Work by Galley et al. (1993) examined in detail the alteration and mineralization of the Chisel and Chisel North orebodies.

Regional geology

The Chisel North deposit is hosted by evolved subaqueous volcanic rocks from the mature portion of the 1.8 to 1.9 Ga Snow Lake arc assemblage (Bailes and Galley, 1999). The northwest-trending synclinal fold interference structure locally known as the Chisel basin is host to the Chisel North orebody, as well as the past-producing Chisel, Photo Lake, Ghost Lake and Lost Lake mines. The Chisel basin is an ~5 km thick arc assemblage comprising mainly mafic wacke, mafic breccia, pillowed basalt and synvolcanic gabbro intrusions. Menard and Gordon (1995) carried out thermobarometric calculations for the Photo Lake mine, located ~2 km northeast of the Chisel North mine. Results suggest that peak P-T conditions reached nearly 535°C at approximately 5 kbar.

Mineralization

The ore typically consists of up to 20 m of silicate-dolomite-rich, semimassive, sphalerite-rich ore with thin interlayers of massive sulphides, and is underlain by discordant zones of disseminated and vein sulphides. Sphalerite and pyrite are the main sulphide phases, although massive pyrrhotite occurs near the hangingwall. The underlying dacite consists of recrystallized, hydrothermally altered rocks now consisting of sericite and chlorite, with common kyanite, biotite, staurolite and garnet porphyroblasts (Galley et al., 1993). The orebody is stratigraphically underlain by a broad, hydrothermal alteration zone hosting sericite- and chlorite-rich lenses containing Zn, Fe, Pb, Cu, As, Au and Ag. Throughout the Chisel basin, the ore horizon is typically overlain by a thick package of mafic wacke. In the no. 4 lens of the Chisel North deposit, the hangingwall of the zinc-rich sulphides is an altered basalt or gabbro body that is locally enriched in Au, Ag, As, Cu and Pb. The nature of this Au-Ag-As-Cu-Pb mineralized zone is still ambiguous.

2006 results

Four days were spent underground mapping and sampling the hangingwall of the no. 4 lens and paying special attention to the nature and intensity of alteration in the hostrock, as well as the presence of sulphide veinlets. The hangingwall of this zone contains highly anomalous values of Cu, Pb, Au, Ag and As, which contrasts with the typical sphalerite-pyrrhotite dominated zinc-rich ore of the mine. Efforts were also dedicated to establishing possible structural controls on the geometry of the mineralized zone.

Squall Lake

The Squall Lake property, owned by Garson Resources Ltd. and located 8 km north of the community of Snow Lake, hosts several lenses of gold mineralization. Exploration on the property started in the mid-1940s. More than 500 exploration holes have been drilled throughout the property and 11 mineralized zones have been identified. Drilling has outlined inferred mineral resources for the Margaret Extension gold occurrence of 100 000 t grading 4.85 g/t Au in the lower silicified zone and 337 000 t grading 5.40 g/t Au in the upper silicified zone (Cavey, 2002). Three bulk samples have also been processed from the Moon-Gertie and Margaret zones.

Previous work

Previous work on the Squall Lake property included mapping by MGS (Ostry, 1990; Schledewitz, 1998). Exploration companies also carried out detailed mapping, trenching, channel sampling and drilling in the area (Cavey, 2002). The most recent drilling was carried out in 2003 by MBMI Resources Inc. (now Garson Resources Ltd.). No detailed study, however, has investigated the nature of the mineralization and its associated alteration.

Regional geology

In the Squall Lake area, the main lithological units are 1) Missi metamorphic suite arkose; underlain by 2) southeast-dipping (25–30°) garnet-staurolite Burntwood metamorphic suite metapelite; and 3) a relatively thick metadiorite sill, now metamorphosed to amphibolite, intruded at the base of the Missi near the contact with the Burntwood metasedimentary rocks. The Squall Lake gold deposit occurs along the northwest limb of the McLeod synform, an F_2 structure. The mineralization host, the diorite sill, is affected by the McLeod fold structure. An east-west regional sillimanite isograd runs across the McLeod syncline but does not show any disturbance from the F_2 fold, suggesting that the peak of metamorphism postdated folding of the mineralized rocks. Thermobarometric calculations for the Squall Lake area were carried out by Kraus and Menard (1997) on Burntwood metamorphic suite metapelite in the vicinity of the deposit. The sample closest to the deposit yielded peak P-T conditions of 605°C and 5.6 kbar (sample #D156-P1; Kraus and Menard, 1997).

Mineralization

The gold mineralization is found in three main zones of subparallel lenses located near the hangingwall contact of the diorite sill (Richardson and Ostry, 1996). The mineralized lenses are found over a stratigraphic thickness of 60 m above the diorite sill. The uppermost zone is hosted within arkosic metasedimentary rocks of the Missi Group and consists mainly of quartz-carbonate stockwork. The middle zone is located at the contact between the diorite sill and the arkosic metasedimentary rocks of the Missi Group. The mineralization occurs as lenses within silicified and slightly carbonatized diorite. The lowermost zone occurs as an ~2 m thick horizon within silicified and carbonatized diorite. Arsenopyrite is the most common sulphide, but highest Au values generally occur in association with chlorite-bearing quartz veins (Richardson and Ostry, 1996).

2006 results

At Squall Lake, large stripped outcrop areas were mapped in detail with special attention being given to the different quartz-vein orientations. Core from six holes drilled in 2003 through the Margaret extension mineralized zone were relogged and sampled. Logging of core enabled the identification of zones of silicification and carbonatization in the dioritic hostrock. Locally, there is a significant increase in biotite abundance in the diorite, suggesting possible potassium enrichment. Reconnaissance mapping was carried on around the nose of the McLeod synclinal structure to collect gabbro and quartz-vein samples and compare their chemistry around the fold nose.

Nokomis Lake

The Nokomis Lake deposit is located along the east shore of Nokomis Lake, 55 km northwest of the town of Snow Lake and 8 km northeast of the Puffy Lake deposit. The property, owned by Pioneer Metals Corporation, is the site of a shear-related intrusive-hosted (tonalite) lode-gold mineralization system associated with quartz veining in a ferrotonalite sill. More than 100 holes, totalling more than 6000 m, have been drilled on the property since exploration began in the 1940s. The most recent drilling was carried out by Claude Resources Inc. in the winter of 2005.

Previous work

The Nokomis Lake area was the subject of detailed mapping during the NATMAP Shield Margin Project (Zwanzig, 1994, 1999). Detailed mapping and drilling were also carried out by exploration companies (Buhlmann, 1997). No study, however, has examined in detail the nature of the mineralization and alteration, and the effect of metamorphism.

Regional geology

The Nokomis Lake property is situated in the Kisseynew Gneiss Belt. Zwanzig (1994) interpreted the amphibolite horizon to be metamorphosed basalt intruded by differentiated gabbro sills that vary in composition from gabbro to ferrotonalite. Zwanzig (1994) indicated that the gold mineralization is hosted in a ferrotonalite horizon. At the Nokomis Lake deposit, a thick sequence of ~190 m of layered amphibolite is structurally overlain by the Burntwood metamorphic suite and underlain by arkosic gneiss of the Missi Group (Zwanzig, 1984).

Mineralization

The gold mineralization is hosted by an ~20 m thick, discontinuous, quartz-bearing tonalite horizon within the amphibolite sequence. The gold is associated with arsenopyrite, although pyrite and pyrrhotite are the main sulphides found in the mineralized horizon. Sulphide veinlets are found toward the base of the mineralized zones. Peloquin et al. (1985) observed that the mineralized zones are subparallel to the gneissic layering. Amphibolite from the Nokomis Lake deposit is traceable over a distance of 8 km (Zwanzig, 1984).

2005–2006 results

At Nokomis, ten holes drilled by Pioneer Metals Corporation in 1997 and 2000 were relogged and sampled, and a dozen old trenches were also visited. Several traverses were carried out across the mineralized horizon to provide samples for P-T work and to get a more general idea of the geological context. Old trenches were visited and mineralized samples collected. In 2005, core samples from older drillholes were also collected for thin section purposes. Preliminary microscope and electron-microprobe work has focused mainly on the sulphide-gold assemblage. Further work will examine textural relationships between sulphide, oxide and silicate minerals. A thermobarometry study of the ore assemblage and the hostrock is also planned.

Preliminary electron-microprobe results have shown that the arsenopyrite (FeAsS) associated with the Au mineralization commonly displays a core of löllingite ($FeAs_2$; Figure GS-4-2). This relationship suggests that the arsenopyrite was late and replaced löllingite, possibly during retrograde metamorphism when sulphur-bearing hydrothermal fluid may have been circulating through the hostrock. Microprobe analyses showed systematic outward increase of the sulphur content in zoned arsenopyrite crystals. Even the löllingite core presented a sulphur-rich rim. Gold was typically found as small (10–300 µm) inclusions within the arsenopyrite grains rather than as free gold in the matrix. Also, most gold inclusions occur at or near the contact between the löllingite core and the arsenopyrite (Figure GS-4-3). Further work will investigate the reaction history of the sulphide minerals and attempt to establish with confidence the evolution of gold.

Puffy Lake mine

The Puffy Lake gold deposit is located within the southern flank of the Kisseynew Domain. The deposit is located about 75 km northeast of Flin Flon and 80 km west of the community of Snow Lake. Hostrocks to the gold mineralization are gneissic supracrustal rocks of medium to high metamorphic grade (Ostry and Halden, 1995). The deposit was first identified by the Hudson Bay Exploration and Development Co. Ltd. in 1960, and was developed by Pioneer Metals Corporation. The mine was in production from December 1987 to March 1989, during which period it produced 991 kg of gold.

Previous work

Zwanzig (1994) carried on detailed mapping in the vicinity of the Puffy Lake mine. Ostry and Halden (1995) studied the gold mineralization underground and recognized two main settings for the gold. Dyck (1997) completed an M.Sc. thesis that addressed the structural complexities and deformation history of the Puffy Lake area.

Regional geology

Within the Puffy Lake area, the Kisseynew Domain comprises the following units: 1) Amisk Group fine-grained amphibolite; 2) greywacke-derived gneiss and migmatite of the Burntwood metamorphic suite; 3) Missi Group fine-grained sedimentary (subgreywacke-arkose) gneiss and, near the base of the unit, intermediate amphibolitic gneiss; and, 4) lineated tonalitic

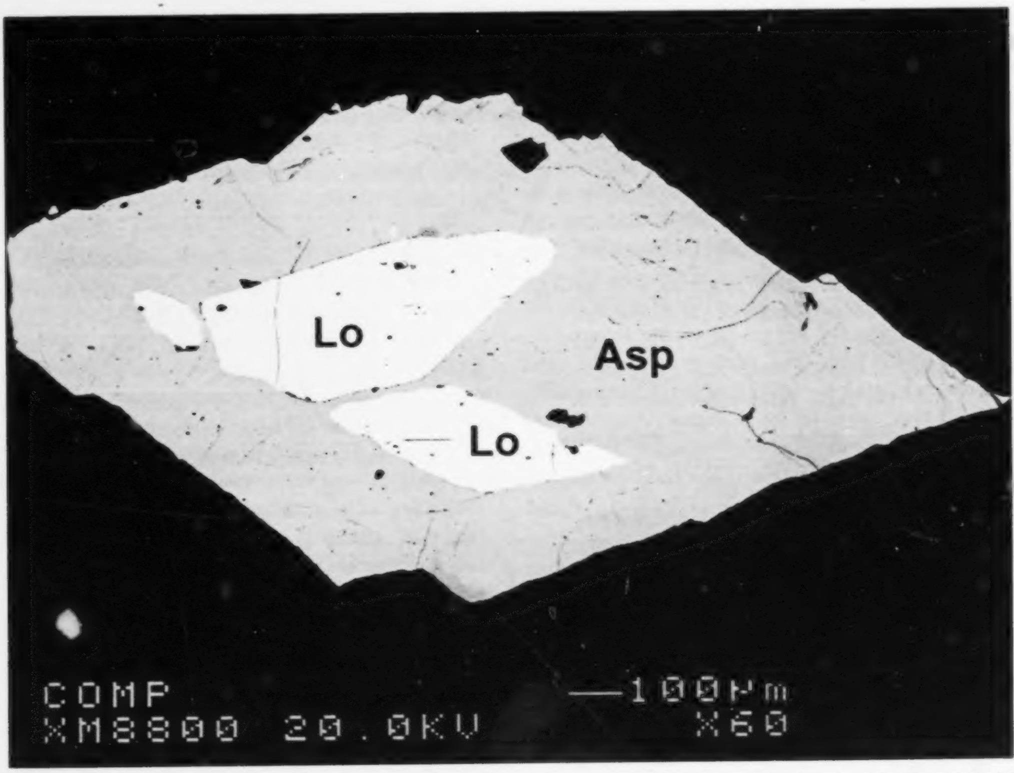

Figure GS-4-2: Back-scattered electron-microprobe image showing a löllingite (Lo) core in an arsenopyrite (Asp) crystal.

minerals. A thermobarometry study of the ore assemblage and the hostrock is also planned.

Preliminary electron-microprobe results have shown that the arsenopyrite (FeAsS) associated with the Au mineralization commonly displays a core of löllingite ($FeAs_2$; Figure GS-4-2). This relationship suggests that the arsenopyrite was late and replaced löllingite, possibly during retrograde metamorphism when sulphur-bearing hydrothermal fluid may have been circulating through the hostrock. Microprobe analyses showed systematic outward increase of the sulphur content in zoned arsenopyrite crystals. Even the löllingite core presented a sulphur-rich rim. Gold was typically found as small (10–300 μm) inclusions within the arsenopyrite grains rather than as free gold in the matrix. Also, most gold inclusions occur at or near the contact between the löllingite core and the arsenopyrite (Figure GS-4-3). Further work will investigate the reaction history of the sulphide minerals and attempt to establish with confidence the evolution of gold.

Puffy Lake mine

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Within the Puffy Lake area, the Kisseynew Domain comprises the following units: 1) Amisk Group fine-grained amphibolite; 2) greywacke-derived gneiss and migmatite of the Burntwood metamorphic suite; 3) Missi Group fine-grained sedimentary (subgreywacke-arkose) gneiss and, near the base of the unit, intermediate amphibolitic gneiss; and, 4) lineated tonalitic

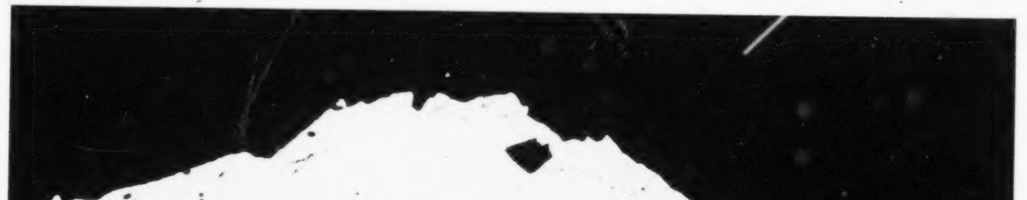

Figure GS-4-2: Back-scattered electron-microprobe image showing a löllingite (Lo) core in an arsenopyrite (Asp) crystal.

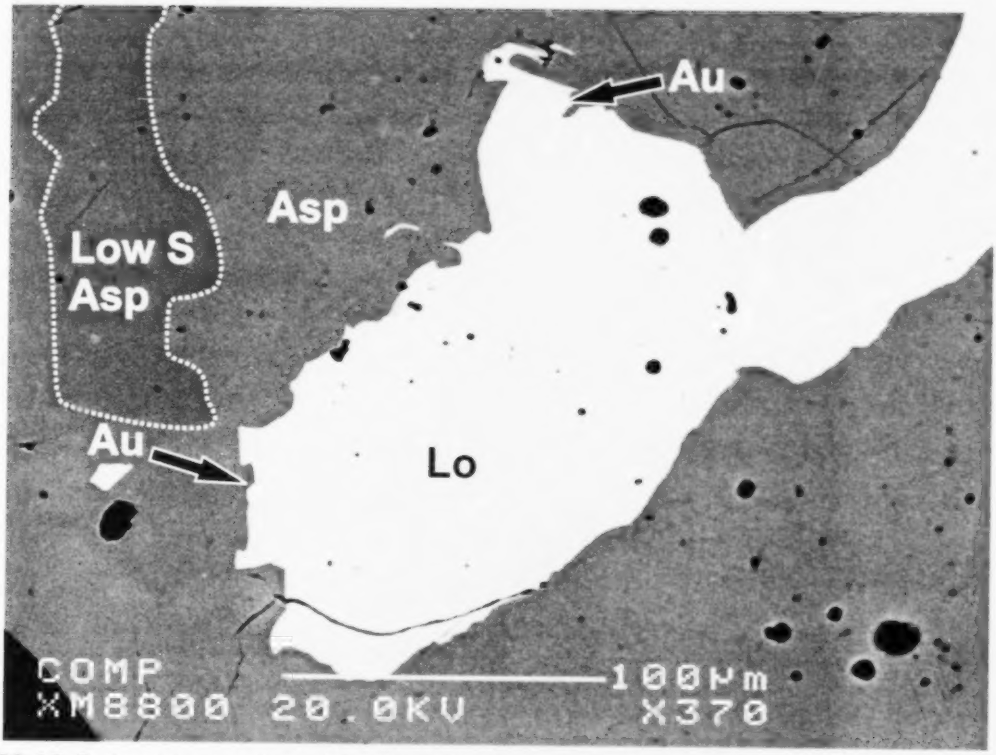

Figure GS-4-3: Back-scattered electron-microprobe image showing a löllingite (Lo) core in an arsenopyrite (Asp) crystal. Arrow points to a gold (Au) inclusion sitting at the boundary between the löllingite and the arsenopyrite. Note also the presence of the low-sulphur zone in arsenopyrite.

gneiss and granitic intrusions. The deposit is located within the core of an anticline folding Burntwood and Missi metasedimentary rocks, and gneissic metavolcanic rocks of the Amisk Group (Zwanzig, 1994). The rocks generally strike north to northwest with a moderate dip (25–40°) and commonly display mineral lineations. The Amisk intermediate to mafic gneiss is interleaved with Burntwood Suite paragneiss. Missi quartzofeldspathic gneiss disconformably overlies the Amisk and Burntwood gneiss. In the Puffy Lake area, peak metamorphic conditions were estimated to have reached 650 to 700°C and 3.5 to 6.5 kbar, based on the presence of the mineral assemblage biotite-garnet-sillimanite-quartz-plagioclase-muscovite south of Puffy Lake and the reaction isograd muscovite + plagioclase + quartz ↔ sillimanite + liquid (melt) in the vicinity of Puffy Lake (Dyck, 1997).

Mineralization

The gold-arsenopyrite-pyrrhotite mineralization with minor chalcopyrite-galena-sphalerite is associated with biotite±hornblende intermediate gneiss layers (Ostry and Halden, 1995). Ostry and Halden (1995) recognized two main settings for the gold mineralization: 1) the 201 type (number referring to the stope where the mineralization was described), which consists of a 1 to 2 m thick mineralized horizon of biotite-rich amphibolite containing abundant disseminated lineated arsenopyrite (up to 20% locally), with minor pyrrhotite and gold; and 2) the 214 type, consisting of a network of anastomosed veins of diopside-biotite-feldspar±quartz containing arsenopyrite, pyrrhotite, pyrite and gold, with traces of chalcopyrite, galena and sphalerite. Crosscutting relationships and the absence of preferred orientation of the sulphide minerals in the 214 type indicate that it is younger than the 201 type. Ostry and Halden (1995) also interpreted the 214-type mineralization to be the result of remobilization of 201-type gold and arsenopyrite during or after the D_1 event. The strong lineation of 201-type arsenopyrite and the presence of a mineral assemblage indicative of a metamorphosed alteration (e.g., assemblage of coarse-grained diopside, Ca-amphibole and calcite associated with sulphide mineralization) strongly suggest a pre–peak metamorphism origin for the deposit (Ostry and Halden, 1995).

2005–2006 results

Reconnaissance mapping of the Puffy Lake property during the summer of 2006 allowed the evaluation of a few trenches; however, no good mineralized exposure could be found. Structural data and unmineralized

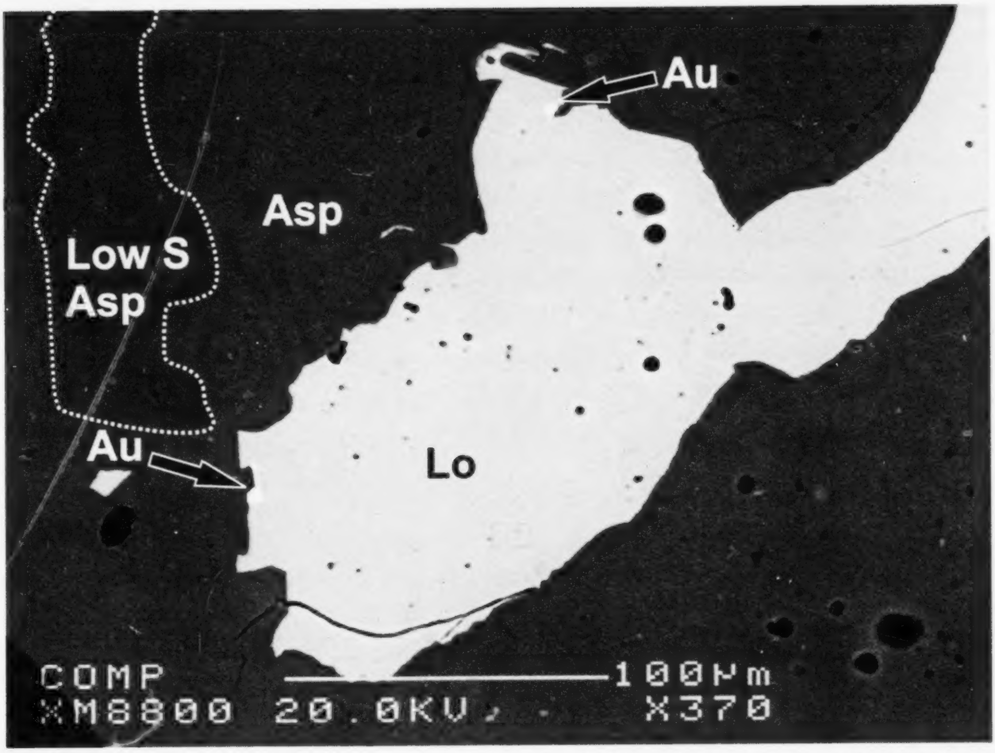

Figure GS-4-3: Back-scattered electron-microprobe image showing a löllingite (Lo) core in an arsenopyrite (Asp) crystal. Arrow points to a gold (Au) inclusion sitting at the boundary between the löllingite and the arsenopyrite. Note also the presence of the low-sulphur zone in arsenopyrite.

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2005–2006 results

Reconnaissance mapping of the Puffy Lake property during the summer of 2006 allowed the evaluation of a few trenches; however, no good mineralized exposure could be found. Structural data and unmineralized samples of various rock types were collected in the vicinity of the minesite for future metamorphic and thermobarometric study. Mineralized samples were also collected from drillcore left on-site, as well as from the ore pile. Samples with a sulphide and silicate mineral assemblage similar to that described by Ostry and Halden (1995) were collected. Oriented samples from underground, provided by G. Ostry, will be used to further investigate the mineralization evolution during metamorphism and deformation. During 2005, core samples from the Puffy Lake mine were collected at the MGS core facility in The Pas.

Preliminary microscope and electron-microprobe work on samples collected in 2005 focussed on the sulphide assemblage. Investigation of Puffy Lake samples showed a sulphide relationship similar to that seen in the Nokomis material. At Puffy, the arsenopyrite is also typically cored by löllingite and gold is commonly found as inclusions located near or at the boundary between the two arsenic-bearing phases. Gold inclusions are generally composed of relatively pure Au (90–95%) in solution with Ag content varying from 5 to 9%. No measurable amounts of Hg, Sb, or Bi were obtained during electron-microprobe analysis of gold inclusions.

Economic considerations

Investigation of sulphide-gold mineralization will provide new constraints on the timing of mineralization and the P-T-t history of the deposit. If the pre–peak metamorphism origin of the mineralization is confirmed, the careful petrographic study of the ore will help provide a better understanding of the mineralogical and compositional consequences of mid-amphibolite-facies metamorphism and migmatization of sulphide-dominated ore. The study will also increase knowledge of sulphide-silicate interaction during prograde metamorphism. Finally, the combination of all these data will allow a better understanding of the evolution of the gold mineralization through prograde metamorphic conditions and clarification of the role of the associated sulphide assemblage. This information will, in turn, provide useful guidelines to help explorationists in the selection of exploration targets in medium- to high-grade metamorphic terranes.

Acknowledgments

Funding for this field season was generously provided by the Manitoba Geological Survey, the Geological Survey of Canada and McGill University. The authors also wish to acknowledge the support of Hudson Bay Mining and Smelting Co. Ltd. for allowing access to the Chisel North underground mine, for kindly providing access to the rock-cutting and core-logging facilities, and for the valuable discussions with the mine staff. S. Gagne would especially like to thank E. Fluskey and S. Snyder, mine geologists at Chisel North, for taking time to guide him underground and explain the deposit. Thanks also go to Pioneer Metals Corporation (Puffy Lake and Nokomis Lake) and Garson Resources Ltd. (Squall Lake) for granting access to their properties and drillcore. The authors also thank J. Filewich and D. Fiegal for their invaluable field assistance. Special thanks go to G. Ostry for allowing the use of his samples and thin sections from Puffy Lake.

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GS-5 Igneous carbonate-rich rocks from the south Wekusko Lake area, Manitoba (parts of NTS 63K9 and 63J12): a kimberlite-carbonatite dilemma

by A. Chakhmouradian[1], C.O. Böhm and J.K. Greville[1]

Chakhmouradian, A., Böhm, C.O. and Greville, J.K. 2006: Igneous carbonate-rich rocks from the south Wekusko Lake area, Manitoba (parts of NTS 63K9 and 63J12): a kimberlite-carbonatite dilemma; *in* Report of Activities 2006, Manitoba Science, Technology, Energy and Mines, Manitoba Geological Survey, p. 49–62.

Summary

The petrography, mineralogy and geochemistry of two macroscopically distinct drillcore samples of 'kimberlitic' rock from the south Wekusko Lake area (central Manitoba) were examined in detail. The two studied samples share a number of textural, modal and geochemical characteristics which strongly suggests that they were derived from similar sources and underwent broadly similar evolutionary histories. Both examined samples show an inequigranular, uniform to segregation texture arising from the presence of abundant macrocrysts (partly or completely chloritized phlogopite, Mg-Al-Cr–rich spinel and Mg-Cr–rich ilmenite) and coarse-grained segregations in a fine-grained dolomitic groundmass. With the exception of Mg-Al-Cr–rich spinel and Mg-Cr–rich ilmenite macrocrysts, the modal and chemical makeup of the examined samples is inconsistent with the identification of these rocks as either group-I or group-II kimberlite. On the basis of their modal, major- and trace-element composition, the Wekusko Lake samples are tentatively identified as magnesiocarbonatite. The majority of phlogopite macrocrysts are cognate with the hostrock and exhibit compositional variation typical of carbonatitic micas. The spinel and ilmenite macrocrysts are compositionally indistinguishable from their counterparts in kimberlites; the latter are routinely used as diamond-indicator minerals in exploration. This similarity (and the concomitant enrichment of the examined samples in Cr, Ni and Co) implies that the Wekusko Lake rocks were derived from a mantle source similar to those that produce kimberlites. The available mineralogical and geochemical evidence indicates that this source was chemically modified (metasomatized) prior to the melting. Further studies of the Wekusko Lake magnesiocarbonatite and its constituent minerals by isotope-analytical techniques will be required to constrain the source and evolutionary history of these rocks.

Introduction

The forty-plus years of intermittent diamond-exploration activity in Manitoba have led to the recognition of several promising targets across central and northern Manitoba, where follow-up work is presently being carried out by a number of senior and junior companies. Nevertheless, only one of these targets, at Wekusko Lake in central Manitoba, has so far been confirmed as 'kimberlite' (see details below). The lack of reliable petrographic, mineralogical and geochemical data on these rocks prompted a re-examination of the material extracted during the initial exploration phase at Wekusko Lake. The present report is a summary of the preliminary findings.

Geological overview of the south Wekusko Lake area

The south Wekusko Lake area is located approximately 20 km southeast of Snow Lake and is accessible by Highways 392 and 39. Geologically, it forms part of the eastern Flin Flon Belt of the Paleoproterozoic Trans-Hudson Orogen (NATMAP Shield Margin Working Group, 1998; Bailes and Galley, 1999; Figure GS-5-1). Most of the supracrustal components of the Flin Flon Belt range in age from 1.91 to 1.88 Ga (Lucas et al., 1996) and represent the products of ocean floor volcanism and arc magmatism (Syme and Bailes, 1993; Stern et al., 1995a, b). Variations in lithology and geochemical associations demonstrate that these sequences are disparate parts of various ocean–floor and arc assemblages, tectonically juxtaposed during intra-oceanic accretion at ca. 1.88 to 1.87 Ga, and subsequent continental collision at ca. 1.84 to 1.79 Ga (Stern et al., 1995b; Lucas et al., 1996).

The tectonic evolution of the Manitoba-Saskatchewan segment of the Trans-Hudson Orogen is believed to have involved diachronous collision of the Archean Rae-Hearne, Superior and Sask cratons, which was largely complete by 1.8 Ga (Hajnal et al., 2005). The collision between the Paleoproterozoic Flin Flon–Glennie Complex[2] (FFGC) and the Sask craton began around, or slightly earlier than, 1.83 Ga, and resulted in south-west-vergent thrusting of the FFGC over the Archean–Siderian rocks (ca. 3.10–2.45 Ga) of the Sask plate along the Pelican thrust (or décollement) zone and intense shear-induced deformation, which continued to at least

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[2] The Paleoproterozoic Glennie Domain in west-central Saskatchewan is geologically similar to the Flin Flon Domain to the east; the two domains are commonly regarded as parts of the Flin Flon–Glennie Complex (Corrigan et al., 2005).

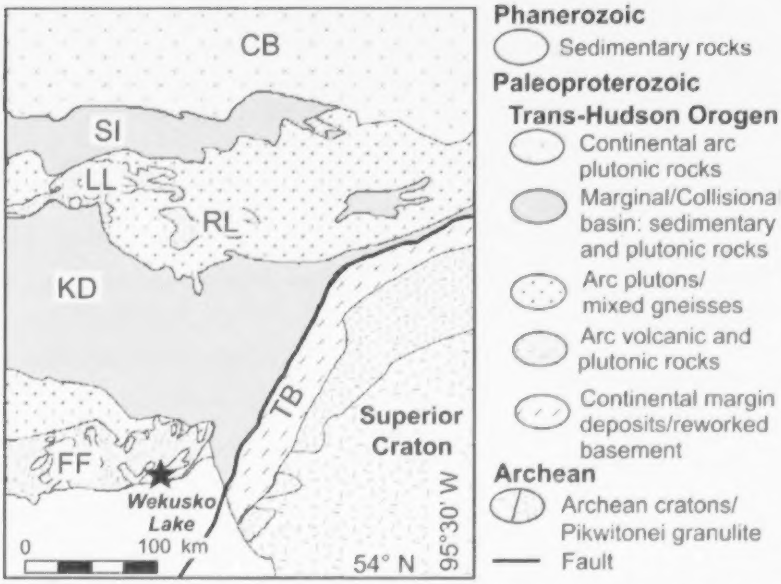
CB
SI
LL
RL
KD
TB
FF
Superior Craton
Wekusko Lake
0
100 km
54° N
95°30' W
Phanerozoic
Sedimentary rocks
Paleoproterozoic
Trans-Hudson Orogen
Continental arc plutonic rocks
Marginal/Collisional basin: sedimentary and plutonic rocks
Arc plutons/ mixed gneisses
Arc volcanic and plutonic rocks
Continental margin deposits/reworked basement
Archean
Archean cratons/ Pikwitonei granulite
Fault

Figure GS-5-1: *Simplified geology of the Wekusko Lake study area (outlined) within the Flin Flon–Snow Lake Belt of the Trans-Hudson Orogen (after Bailes and Galley, 1999). Abbreviations: CB, Chipewyan Batholith; FF, Flin Flon–Snow Lake Belt; KD, Kisseynew Domain; LL, Lynn Lake Belt; RL, Rusty Lake Belt; SI, Southern Indian Domain; TB, Thompson Belt.*

1806 Ma (Ashton et al., 1999, 2005; Ansdell, 2005; Bickford et al., 2005). Post-collisional shortening ca. 1.80 to 1.77 Ga, manifested in F3 folds, is typically attributed to the continuing convergence of the Sask and Superior cratons at depth, (i.e., below the FFGC; Ashton et al., 2005). The relative extent of the Archean rocks underplating the FFGC is largely unknown; the recent seismic-reflection and radio-isotope studies indicate that the Sask substructure extends beneath at least 100 000 km^2 of the Trans-Hudson Orogen, including the FFGC (Bickford et al., 2005; Hajnal et al., 2005).

Bedrock exposures in the south Wekusko Lake area are dominantly metavolcanic and metasedimentary supracrustal rocks intruded by granitoid rocks and overlain by Ordovician dolomite as outlined and described in Gilbert and Bailes (2005; Figure GS-5-2). The supracrustal rocks in the study area are distinct tectonostratigraphic supracrustal components (south Wekusko Lake, Hayward Creek, Burntwood Group; Figure GS-5-2). They form part of a structurally complex collage of Paleoproterozoic volcanic juvenile arc, arc rift, ocean floor and oceanic island assemblages, and sedimentary and minor volcanic deposits. At south Wekusko Lake, the north- to north-northeast-trending Crowduck Bay Fault (Ansdell and Connors, 1993; Gilbert and Bailes, 2005) traverses the south Wekusko Lake ocean floor basalt sequence. A subparallel, possible splay of the fault marks the eastern boundary of a domain, several kilometres wide, of 1.85 to 1.84 Ga (David et al., 1996) Burntwood Group greywacke, siltstone and mudstone turbidite and derived paragneiss (Figure GS-5-2).

The South Wekusko Lake domain is a <4 km wide, east-facing ocean floor volcanic sequence that comprises pillowed, aphyric, tholeiitic basalt flows, related gabbro sills and mafic phyllonite (Gilbert and Bailes, 2005). The Hayward Creek domain (Gilbert, 1994) comprises juvenile arc volcanic rocks including basalt, mafic fragmental rocks, mixed felsic flows and fragmental rocks, and volcaniclastic greywacke and mafic tuff (Gilbert and Bailes, 2005). This lithologically diverse suite is geochemically akin to 1.89 Ga (David et al., 1996) volcanic rocks of the Snow Lake arc assemblage of Bailes and Galley (1999). The Burntwood Group sedimentary rocks at south Wekusko Lake include mainly greywacke, siltstone and mudstone turbidites that are fault-bound between the south Wekusko Lake and the Hayward Creek volcanic domains (Figure GS-5-2).

The 1.84 to 1.83 Ga southwest Wekusko Lake pluton forms an ovoid, mainly tonalite–quartz diorite body that structurally stitches together the Hayward Creek and Burntwood Group domains at the southwest end of Wekusko Lake (Figure GS-5-2; Gilbert and Bailes, 2005). The youngest intrusive rocks in this area include anorthositic gabbro and quartz gabbro (Gilbert and Bailes, 2005) and 'kimberlitic dikes', the latter being the focus of this report.

The above bedrock exposures are unconformably overlain by irregularly shaped outliers of flat-lying Ordovician dolomite up to several square kilometres in size (Figure GS-5-2; Gilbert and Bailes, 2005). Exposures of the Precambrian–Phanerozoic boundary are generally

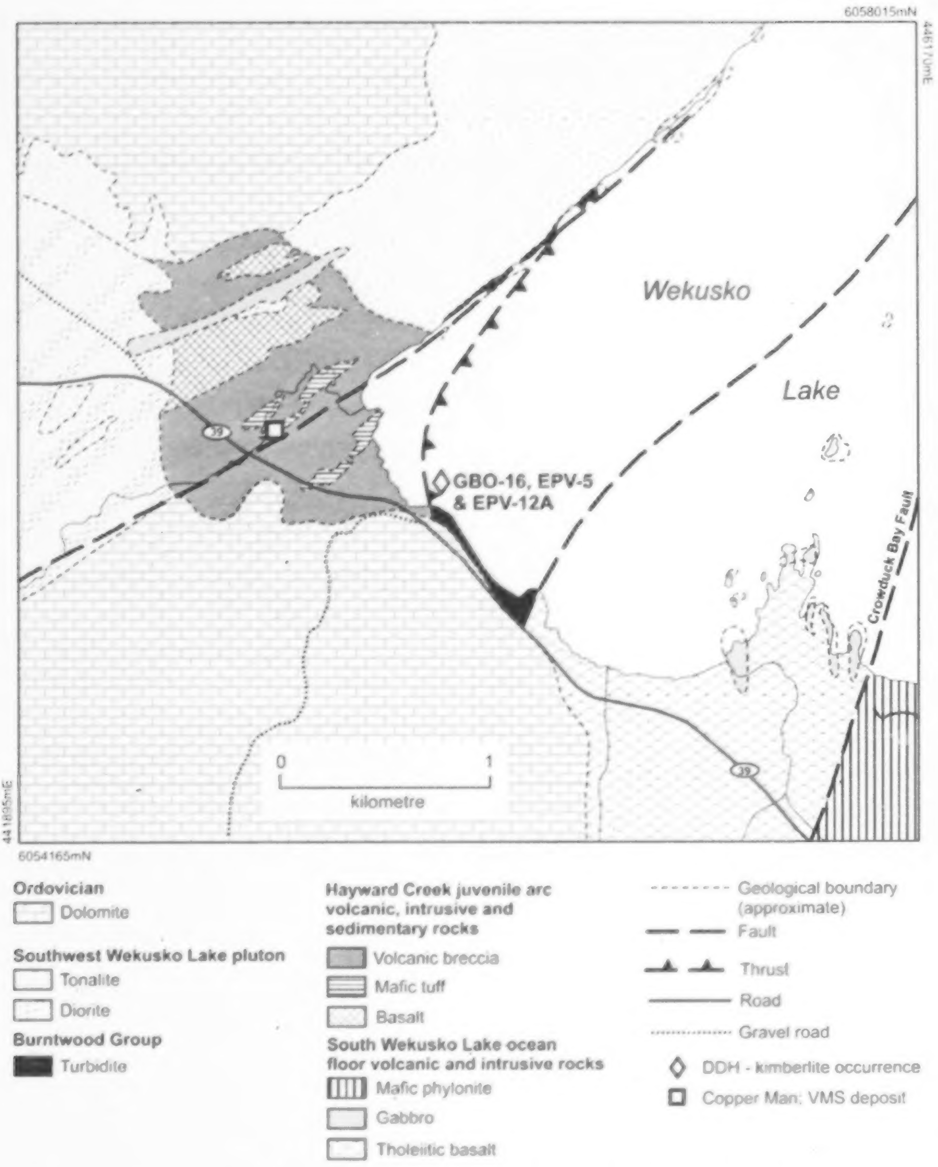
6058015mN
446170mE
Wekusko
Lake
39
GBO-16, EPV-5
& EPV-12A
Crowduck Bay Fault
0
1
kilometre
441895mE
6054165mN
Ordovician
Dolomite
Southwest Wekusko Lake pluton
Tonalite
Diorite
Burntwood Group
Turbidite
Hayward Creek juvenile arc volcanic, intrusive and sedimentary rocks
Volcanic breccia
Mafic tuff
Basalt
South Wekusko Lake ocean floor volcanic and intrusive rocks
Mafic phylonite
Gabbro
Tholeiitic basalt
Geological boundary (approximate)
Fault
Thrust
Road
Gravel road
DDH - kimberlite occurrence
Copper Man: VMS deposit

***Figure GS-5-2**: Simplified geology of the southwest Wekusko Lake area (after Gilbert and Bailes, 2005).*

rare in Manitoba, but south Wekusko Lake represents an area where this unconformable boundary is accessible in many places.

Chronology of the Wekusko Lake 'kimberlite' core samples

Falconbridge Nickel Mines Ltd. first intersected a brecciated rock of uncertain petrographic affinity during their 1983 drilling program focused on the Copper Man VMS deposit (Golden Bounty option) in the southwest section of Wekusko Lake. The problematic rock was intersected in drillhole GBO-16 within Burntwood Group greywacke, just offshore from the VMS deposit (Figure GS-5-2). Kimberlite is not reported in the original drill log; however, the interval in question (263–280 ft.) was described as "breccia, fine to medium grained, light grey matrix with up to 10% granule and pebble-sized fragments of dolomite, siltstone and mudstone. Some of the fragments are angular to sub-angular; others are subrounded to rounded. The matrix is soft and crumbly. Core is extremely broken. Contains occasional pyrope garnets" (Assessment File 70569, Manitoba Science, Technology, Energy and Mines, Winnipeg). This core was stored at Falconbridge's Anderson Bay core storage facility in Snow Lake, and was retrieved by D. Prouse

(Manitoba Geological Survey) in the summer of 2003.

In the winters of 1992 to 1994, European Ventures Inc. (now Firestone Ventures Inc.) drilled a series of holes in the southwest Wekusko Lake area, following up on the reported garnet-bearing breccia intersected in the Falconbridge Nickel Mines drillhole GBO-16. Three of the European Ventures drillholes (EPV-5-93, EPV-12A-94 and EPV-17-94) intersected a 'kimberlitic' rock. The EPV-12A drillhole intersected a short section of 'kimberlitic' rock and showed weak conductivity, which was attributed to chloritic muddy gouge on both walls. The drillhole logs for EPV-12A and EPV-17 are attached to Assessment File 73676 (Manitoba Science, Technology, Energy and Mines, Winnipeg) and the core for EPV-12A was submitted to The Pas core storage facility. The drillhole log for EPV-5 was not attached. The log description at 106.5 to 107.3 m in drillhole EPV-12A mentions "kimberlite dike — breccia, fine to medium grained, brown, vuggy". The 0.5 m wide dike intersection at 43.8 m in drillhole EPV-17 is described as "brown-pitted, slight red tinge — diopside crystals" and is identified as being "visually identical to the dike intersected by holes EPV-5 and 12A" (A.F. 73676).

A European Ventures press release of July 26, 1993, refers to a report by Gurney and Zweistra (1993) stating that "G10, G9 and possible DI (diamond inclusion) eclogitic garnets have been identified by microprobe analyses of concentrate from a 5.2 kg kimberlite sample intersected near Snow Lake" (European Ventures Inc., 1993). This was followed up by a brief note on The Diamond Page in The Northern Miner from March 28, 1994, reporting that "European Ventures (VSE) has intersected a narrow kimberlite dike on Wekusko property near Snow Lake, Man. A 5 kg sample containing indicator minerals has been sent for microdiamond analysis" (The Northern Miner, 1994).

The small remaining portions of the 'kimberlitic' interval of the original Falconbridge core (GBO-16) were recovered and studied by the Manitoba Geological Survey (2003). Based on thin sections, the small samples present were interpreted as carbonatite and were subsequently processed for U-Pb perovskite age dating at the University of Alberta Radiogenic Isotope Facility. Two mineral fractions were analyzed but likely contained rutile and/or chromite together with, or instead of, perovskite. Consequently, the U-Pb and Pb-Pb isotopic analyses are dominated by common lead (^{204}U) and therefore provided no clear age result (Böhm and Heaman, unpublished data, 2004).

In spring 2005, P. Holden (Gossan Resources Ltd.) provided R. Syme (Manitoba Geological Survey) and subsequently the authors of this report with additional material from the Wekusko Lake drillcore. This material is believed to have come from the intersection of kimberlitic rock in the European Ventures drillhole EPV-12A-94 (A.F. 73676). The material studied in this work included two fragments of the EPV-12A-94 drillcore (20 g each) and several fragments of GBO-16 drillcore (ca. 60 g in total).

Petrography

The petrography of samples EPV-12A-94 and GBO-16 was studied in conventional and polished thin sections using polarizing optical microscopy, back-scattered electron (BSE) imaging and energy-dispersive x-ray spectrometry (EDS). The two samples differ in macroscopic colour (brownish grey and greyish green, respectively), but share a number of textural and modal characteristics, including

- inequigranular, slightly vesicular uniform to segregation texture consisting of macrocrysts[3] (0.2–2.5 mm) set in a fine-grained carbonate matrix (Figure GS-5-3);
- the preponderance of teal green (emerald green in hand specimen) chlorite (± its precursor phlogopite) among macrocrysts, followed by chromian spinel[4] and magnesian ilmenite;
- the bulk of the groundmass being composed of turbid carbonate material with indiscernible grain boundaries, which locally grades into larger (up to 300 µm in size) clear rhombohedral crystals lining vesicles and macrocryst boundaries;
- the presence of fragmented clastic material (predominantly quartz); and
- ubiquitous reaction textures (e.g., replacement of phlogopite by chlorite).

Textural evidence indicates that chlorite is not a primary mineral in these rocks, and that it developed at the expense of phlogopite macrocrysts (Figure GS-5-3c). Within a relatively small area, all gradations from unaltered phlogopite (yellowish orange, bright interference colours) to complete pseudomorphing of phlogopite by chlorite (teal green, anomalous interference colours) can be found (Figures GS-5-3a, d), suggesting a very localized nature of replacement reactions. Although fresh phlogopite was not observed in EPV-12A-94, the chlorite macrocrysts are identical in both samples and were probably formed through the same process. Sample GBO-16 contains a higher modal percentage and a greater variety of macrocrysts, including phlogopite, zircon and fluorapatite. Zircon is nearly as common as ilmenite in that sample, and is readily recognizable by its high

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[3] In this report, the term 'macrocryst' is preferred to such genesis-specific terms as microphenocryst, xenocryst, etc., because the potential source (or sources) of this material remains undetermined.

[4] Consistent with the conventionally used kimberlite terminology, the name 'spinel' here refers to spinel-group minerals sensu lato.

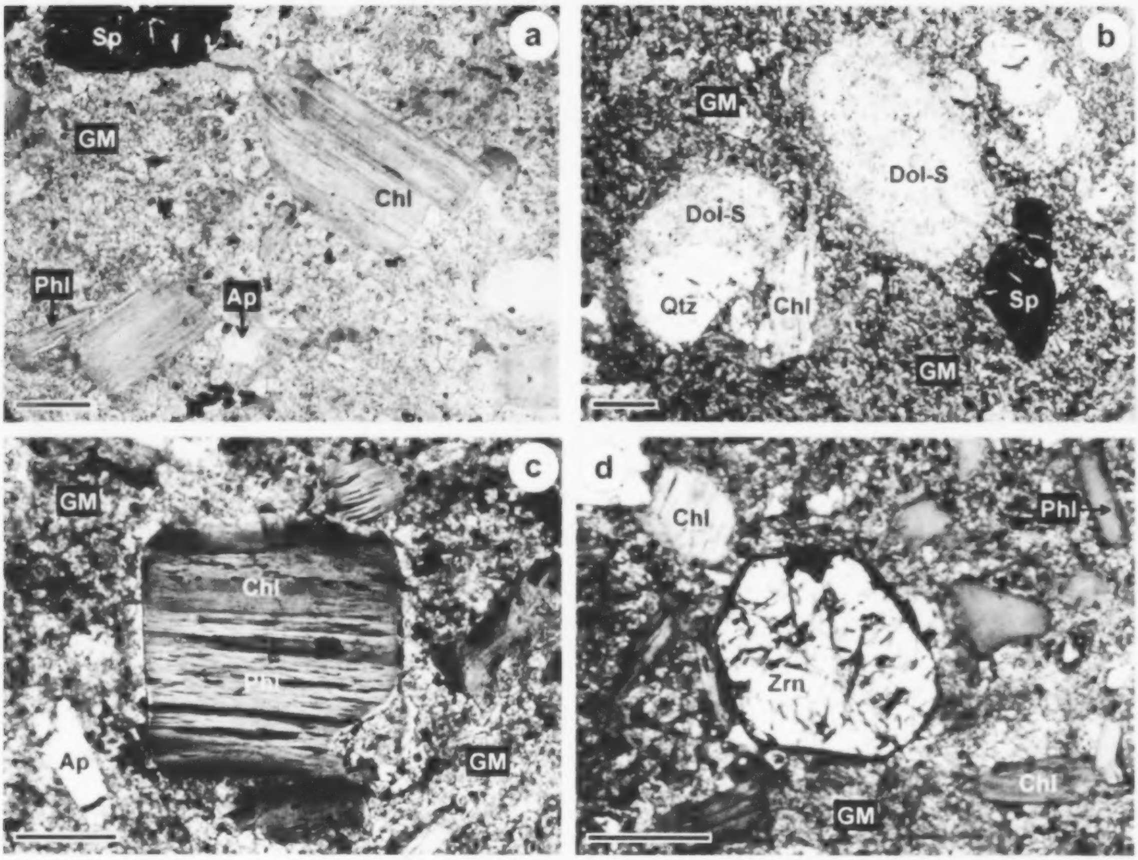

***Figure GS-5-3:** Textural characteristics of samples GBO-16 (a, c, d) and EPV-12A-94 (b), as seen in thin section in plane-polarized light. Scale bar is 200 μm in (a) and (c) and 500 μm in (b) and (d). Note the presence of chlorite (Chl), phlogopite (Phl), spinel (Sp), fluorapatite (Ap) and zircon (Zrn) macrocrysts in a predominantly dolomitic groundmass (GM). Sample EPV-12A-94 also features ovoid segregations of relatively coarser-grained dolomite (Dol-S) and quartz clasts (Qtz).*

birefringence and a thin opaque rim (Figure GS-5-3d). In addition to the macrocrysts, sample EPV-12A-94 contains abundant ovoid segregations (0.5–2.5 mm across) of coarser-grained dolomite and angular fragments of quartz (Figure GS-5-3b) and Al-Ti–rich biotite. Dolomite segregations are also present in GBO-16, but these invariably host numerous crystals of (chloritized) phlogopite.

Mineral chemistry

The chemical compositions of all minerals were determined in polished thin sections by wavelength-dispersive x-ray spectrometry (WDS) using a fully automated Cameca SX100 electron microprobe. The bulk of both studied samples is made up of dolomite with variable proportions of an ankerite component in its composition (3–22 mol % $CaFe(CO_3)_2$). Variations in the Mg/Fe ratio result in intricate growth zoning detectable only in BSE images (Figure GS-5-4a). The highest FeO content (8.3 wt. %) is observed in the core of large crystals from GBO-16, which also show appreciable levels of SrO (0.3–0.6 wt. %). The low-Fe dolomite compositions overlap in the two samples. The MnO content is systematically low ($\leq$1.4 wt. %), and Ba is below the detection limit of WDS (500 ppm).

Phlogopite macrocrysts and crystals from segregations exhibit a wide compositional range (mg#[5] = 0.64–0.85, Al_2O_3 = 8.8–14.9 wt. %, TiO_2 = 0.1–1.9 wt. %, Cr_2O_3 $\leq$0.06 wt. %, BaO $\leq$0.5 wt. %, MnO = 0.08–0.22 wt. %, F = 0.6–1.4 wt. %), indicating that they equilibrated at different P-T conditions or were derived from different sources. None of these igneous compositions, however, overlap with that of Al-Ti–rich biotite xenocrysts observed in sample EPV-12A-94 (mg# ≈ 0.35, Al_2O_3 ≈ 18.0 wt. %, TiO_2 ≈ 3.4 wt. %, F ≈ 0.4 wt. %). Similar to quartz, the biotite xenocrysts clearly represent crustal material, but it remains to be determined whether this

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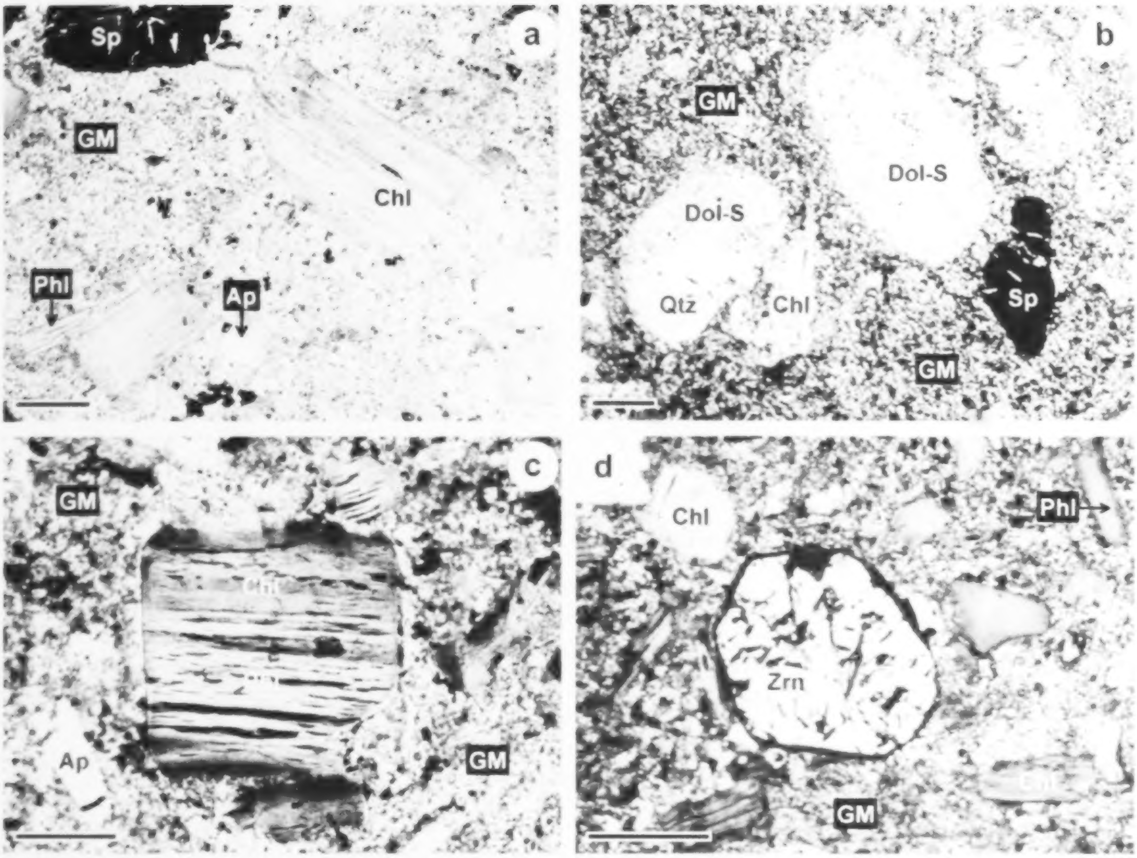
[5] mg# = Mg/(Mg+Fe_Σ)



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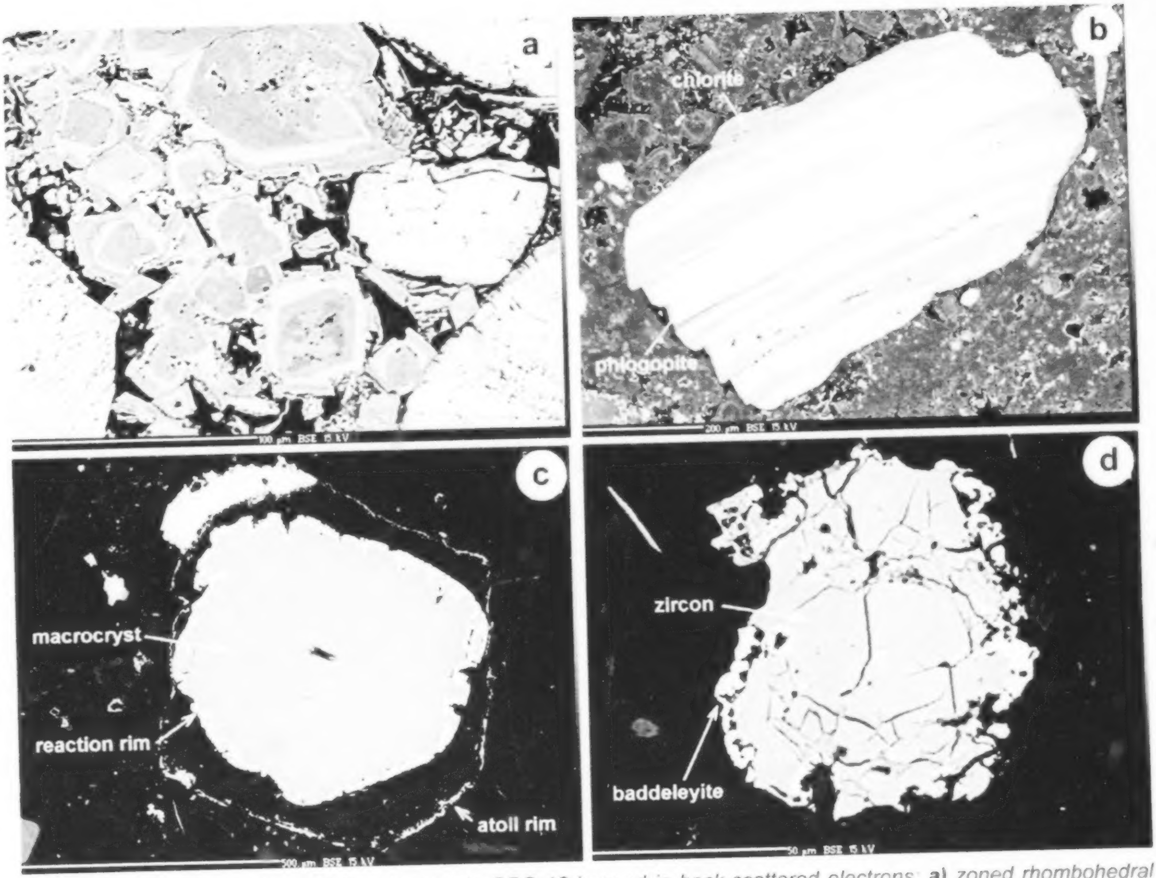
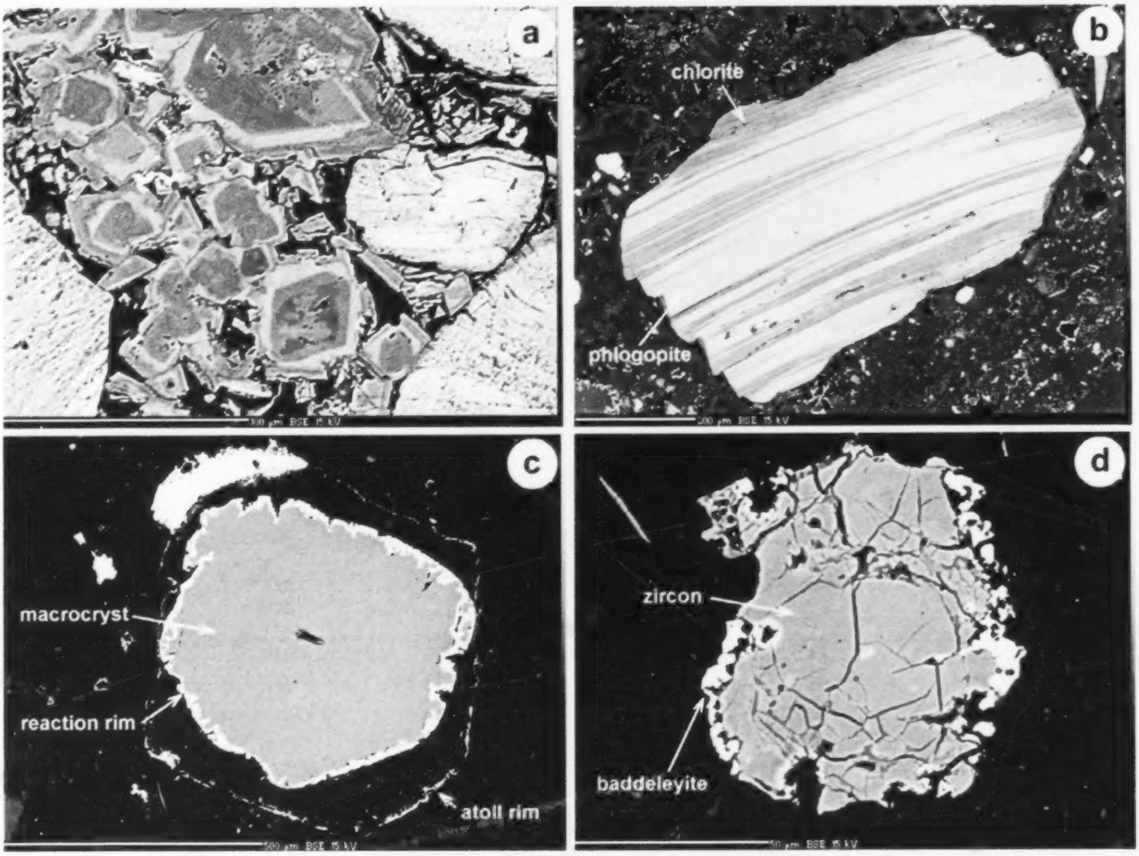


Figure GS-5-4: Mineral interrelations in sample GBO-16 imaged in back-scattered electrons: ***a)*** *zoned rhombohedral dolomite crystals and chloritized phlogopite form segregations;* ***b)*** *phlogopite macrocryst partly replaced by chlorite (dark grey);* ***c)*** *atoll-like spinel macrocryst showing a Mg-Al-Cr–rich core (dark grey) and a Fe-Ti–rich rim (white);* ***d)*** *fractured zircon crystal (dark grey) mantled by Zr oxides (white).*

material was derived from the surrounding metasedimentary rocks or deeper crustal levels. Chlorite, developed after the primary phlogopite (Figures GS-5-3c, 4b), covers a range of compositions that is remarkably similar to the phlogopite range in terms of key chemical parameters: mg# = 0.64 to 0.84, Al_2O_3 = 10.8 to 14.3 wt. %, TiO_2 = 0 to 1.4 wt. %, F = 0.6 to 1.2 wt. % (cf. phlogopite above). Chlorite macrocrysts from sample EPV-12A-94 are generally similar, but have slightly higher mg# (0.68–0.88). These data indicate that most, if not all, of the chlorite in the examined samples is the product of phlogopite replacement, whereas low-grade metamorphic chlorite is characteristically lacking.

Spinel and **ilmenite** are both important minerals from the standpoint of mineral exploration (see below). Spinel macrocrysts are dark brown to opaque in plane-polarized light and show a relatively simple zoning pattern in BSE images; some crystals also exhibit a well-defined atoll texture (Figure GS-5-4c). The core of large macrocrysts is enriched in MgO, Al_2O_3 and Cr_2O_3 (10.0–13.4, 11.1–21.9 and 46.7–55.6 wt. %, respectively), and low in TiO_2 (≤1.0 wt. %, but undetectable in the most Mg-Al-Cr–rich compositions). Back-scattered electron (BSE) imaging reveals that many macrocrysts are fragments of larger crystals showing variations in MgO, Al_2O_3 and TiO_2 contents. In these cases, enrichment in TiO_2 is invariably accompanied by depletion in MgO and Al_2O_3. In comparison with the core, the narrow outer rim of the large macrocrysts (Figure GS-5-4c) and smaller grains are depleted in MgO and especially Al_2O_3 (4.6–7.4 and ≤1.2 wt. %, respectively), but enriched in TiO_2 (up to 7.0 wt. %) and ($FeO+Fe_2O_3$). The earliest compositions to crystallize are ternary spinels with roughly equal proportions of $MgAl_2O_4$, $MgCr_2O_4$ and $FeCr_2O_4$, but with a general predominance (35–45 mol %) of the latter component. The later-crystallized Ti-rich Mg-Al–depleted compositions contain nearly equal proportions of $MgCr_2O_4$, $FeCr_2O_4$ and $FeFe_2O_4$ (20–40 mol %) at low to moderate $TiFe_2O_4$ and low $MgAl_2O_4$ contents. Ilmenite shows little variation in chemistry. It is characteristically rich in MgO and Cr_2O_3 (9.3–10.0 and 1.6–2.6 wt. %, respectively), but poor in MnO and Nb_2O_5



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(0.4–0.5 and ≤0.2 wt. %, respectively). All of the analyzed grains contain an appreciable proportion of oxidized iron (~20% of all Fe is Fe^{3+}, or 8 mol % Fe_2O_3).

Fluorapatite (i.e., apatite, in which F is the dominant monovalent anion) contains small but measurable concentrations of Na, Sr and rare earth elements (up to 0.5 wt. % Na_2O, and 1.1 wt. % SrO and Ce_2O_3+La_2O_3+Nd_2O_3). Other elements of petrogenetic significance (Si, S, Ba and Cl) are either at or below the detection limit of WDS.

Zircon macrocrysts contain only minor amounts of HfO_2 (1.1–1.4 wt. %); other potential substituents (Ca, Fe, Ti, Th, U, Nb, Ta, Y and Al) were sought, but not detected. The opaque rim, clearly visible in plane-polarized light, is discontinuous (Figure GS-5-4d) and consists of two or more Zr oxides. The size of individual grains is too small for these minerals to be confidently identified, but the bulk of this material is probably baddeleyite (ZrO_2).

Geochemistry

Random off-cuts of samples EPV-12A-94 and GBO-16 (~7 g each) were cleaned, pulverized and analyzed for major and trace elements at Activation Laboratories Ltd. (Ancaster, Ontario). 'Randomization' was deemed impractical because of the fine-grained nature of the samples (*see* 'Petrography' section) and scarcity of material. Conventional lithium–borate fusion and inductively coupled plasma techniques were used for all major and trace elements except CO_2 (determined by coulometry).

Both studied samples have the same major- and trace-element signature:

- high MgO, CaO and CO_2 (>20 wt. % each), moderate SiO_2 and $(Fe_2O_3)_\Sigma$ (3–8 wt. %), and low TiO_2, Na_2O, K_2O and MnO contents (<1 wt. %); the Al_2O_3 and P_2O_5 values are low in EPV-12A-94, but appreciable in GBO-16 (2.6 and 1.5 wt. %, respectively) owing to the much greater abundance of phlogopite, chlorite and fluorapatite in the latter
- high concentrations of compatible trace elements (42–98 ppm Sc, 42–87 ppm V, 28–112 ppm Co, 910–990 ppm Cr and 380–610 ppm Ni)
- high concentrations of 'incompatible'[6] trace elements, particularly Sr (173–674 ppm), light rare earth elements ($LREE_\Sigma$ = 351–878 ppm), Nb (162–189 ppm), Zr (270–290 ppm), Th (60–100 ppm) and U (19–22 ppm)
- high Nb/Ta and Zr/Hf ratios (>21 and 48, respectively), but a low Zr/Nb ratio (1.5–1.7) relative to the primitive-mantle composition (McDonough and Sun, 1995)
- primitive Y/Ho ratio (25–28)

The trace-element compositions of the two rocks are remarkably similar: both show moderate enrichment in LREE relative to heavy REE, strong negative Rb-Ba, K, Zr-Hf and Ti anomalies and moderate-to-strong Pb and Sr anomalies (Figure GS-5-5).

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[6] The term 'incompatible element' is misleading when used in the context of small-volume mantle-derived rocks (e.g., kimberlite, carbonatite, etc.), because most of these elements behave compatibly with respect to the primary minerals crystallizing from such magmas (phlogopite, perovskite, pyrochlore, etc.).

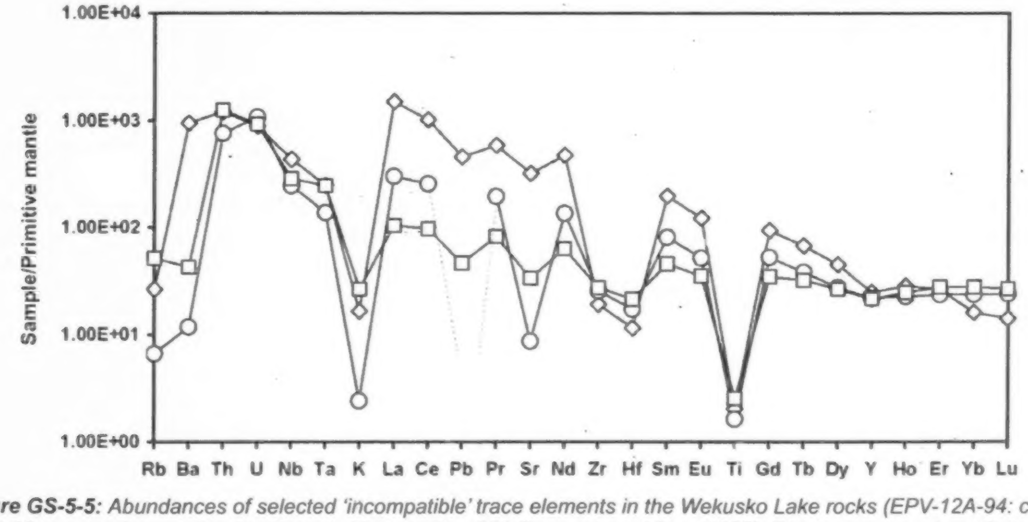

***Figure GS-5-5:** Abundances of selected 'incompatible' trace elements in the Wekusko Lake rocks (EPV-12A-94: circles; GBO-16: squares) normalized to the primitive mantle of McDonough and Sun (1995). The 'average carbonatite' pattern (Chakhmouradian, unpublished data) is shown for comparison (diamonds).*

Discussion

The accumulated petrographic, mineralogical and geochemical evidence indicates that samples EPV-12A-94 and GBO-16 were derived from similar sources and underwent broadly similar evolutionary histories. The observed differences in texture and modal mineralogy are difficult to explain in terms of a single petrogenetic process (e.g., crystal fractionation or vapour release), and it is more likely that the two rocks are different (but related) intrusion phases rather than different facies derived from the same magma batch. In either case, EPV-12A-94 is the more evolved of the two, as indicated by the greater abundance of carbonate segregations, lower abundance of macrocrysts, complete conversion of phlogopite to chlorite, and higher Zr/Hf, Nb/Ta and $LREE_{\Sigma}$ values in this sample. At this point, any attempt to constrain the exact source and evolutionary paths of the magmas that produced the Wekusko Lake 'kimberlitic' rocks would be premature. The presently available data, however, will allow some important conclusions to be drawn about the nature of these rocks and their economic potential.

Kimberlite-carbonatite dilemma

It has long been recognized that several types of mantle-derived volatile-rich and silica-undersaturated rocks (e.g., ultramafic lamprophyre, silicocarbonatite and melilitite) are texturally, modally and chemically akin to kimberlite. The similarity in texture reflects the similarity of processes involved in the emplacement of alkali- and volatile-rich silica-undersaturated magmas at shallow crustal levels. The similarity in mineralogy and/or whole-rock chemistry is only apparent and may be readily refuted upon a detailed examination and comparative analysis. Further discussion of this subject is beyond the scope of the present report; interested readers are referred to the discussions in Mitchell (1986), Mitchell (1995), Mitchell et al. (1999), Taylor and Kingdom (1999) and Tappe et al. (2005). It is important to note that, not only kimberlite (sensu lato), but also such mantle-derived rocks as lamprophyre and carbonatite may contain significant concentrations of diamond (e.g., Djuraev and Divaev, 1999; Kornilova et al., 1999; Litvin et al., 2001; Tappe et al., 2004; De Stefano et al., 2006).

It is quite clear that the two samples studied in the present work are *not* group-I kimberlite, because they completely lack macrocrystic and (micro)phenocrystic olivine (as well as serpentine or any other products of olivine alteration), and are composed largely of dolomite (70–85% by weight). In group-I kimberlite, calcite is the principal carbonate mineral present as (micro)phenocrysts, groundmass grains, segregations and secondary alteration products (Dawson and Hawthorne, 1973; Mel'nik et al., 1982; Podvysotskii, 1985; Armstrong et al. 2004). Primary dolomite is much less common and, where present, forms (reaction) mantles and overgrowths on earlier crystallized calcite (e.g., Chakhmouradian and Mitchell, 1999; Armstrong et al., 2004). Even evolved macrocryst-poor and carbonate-rich varieties of kimberlite (sometimes incorrectly referred to as carbonatite) are composed predominantly of calcite (Dawson and Hawthorne, 1973; Beard et al., 2000). Late-stage dolomite, developed at the expense of olivine (and, to a lesser degree, other Mg-Fe minerals) contemporaneously with serpentine, is much more common (e.g., Mel'nik et al., 1982), but texturally distinct from the groundmass and segregation dolomite observed in the Wekusko Lake samples. To the best of the authors' knowledge, the only reported example of kimberlite with predominantly dolomitic groundmass is a dike in Keith Township (Ontario), described by Watson et al. (1978). It is noteworthy, however, that 1) the identification of carbonate in that rock as dolomite was based solely on x-ray powder diffraction data, and 2) the modal composition of the Keith Township dike is not entirely consistent with that of typical kimberlite. Also noteworthy is the absence in the present samples of poikilitic groundmass phlogopite, monticellite, perovskite, and Mg-poor ulvöspinel-magnetite (titanomagnetite), the 'hallmark' minerals of group-I kimberlite (Mitchell, 1986, 1995).

Group-II kimberlite, also referred to in the literature as micaceous kimberlite or orangeite (Mitchell, 1995), is a rare type of ultrapotassic volatile-rich (primarily, H_2O-rich) rock ranging in composition from unevolved ultramafic varieties with <38 wt. % SiO_2, <4 wt. % Al_2O_3 and >21 wt. % MgO to evolved varieties containing >41 wt. % SiO_2, >4 wt. % Al_2O_3 and <21 wt. % MgO. Evolved group-II kimberlite is compositionally similar to olivine lamproite (except for somewhat higher Ba and Zr in the latter), whereas unevolved varieties can be distinguished from olivine lamproite by their lower SiO_2, and higher CaO and CO_2 contents. It is more difficult to discriminate between group-I and group-II rocks on the basis of whole-rock chemistry (Mitchell, 1995). Unevolved group-II kimberlite is generally richer in K and poorer in Ti, although there is much overlap between the two rock types below 1.5 wt. % K_2O and TiO_2. The enrichment of group-II kimberlite in K and depletion in Ti are reflected in the mineralogy of these rocks, including the presence of ubiquitous macrocrystic, microphenocrystic and groundmass phlogopite, and paucity of Mg-Ti–rich spinel. Group-II rocks may also contain an assortment of exotic minerals (e.g., aegirine, Ti-Zr garnet, Ba and REE carbonates) that are not observed in either group-I kimberlite or olivine lamproite. Thus far, true orangeite has been observed only in southern Africa. Most of these occurrences are restricted to the Kapvaal craton, and range from 110 to 200 Ma in age (Skinner, 1989). The only economically diamondiferous (0.4–0.5 ct/tonne) group-II kimberlite is the Finsch pipe, 165 km west of Kimberley, South Africa.

Group-II kimberlite occurrences from the Bellsbank field in South Africa have been reported to contain a high proportion of dolomite, to the extent where it is the principal constituent in the groundmass (Mitchell, 1995, p. 245). It is important to note, however, that this groundmass dolomite is believed to have replaced serpentine, and fresh samples contain more serpentine than dolomite (Mitchell, 1995, p. 245). A similar mechanism has been proposed for shallow dolomite-rich portions of the Finsch pipe (Ruotsala, 1975). In contrast, the authors found no indication that the groundmass dolomite in the Wekusko Lake samples developed at the expense of serpentine or any other mineral. The composition of macrocrystic phlogopite in the two studied samples partly overlaps with the compositional range of mica from group-I and group-II kimberlite; however, phlogopite compositions with mg# <0.75 are virtually absent from group-I rocks and restricted to extremely Al-depleted Fe (±Ti)–rich mica in group-II kimberlite ('orangeite tetra-ferriphlogopite trend' of Mitchell, 1995; *see also* Taylor and Kingdom, 1999; Kaminsky et al., 2004; Masun et al., 2004). The compositional range of spinel macrocrysts from the Wekusko Lake rocks overlaps that of macrocrystic spinel from group-I and group-II kimberlites (Mitchell, 1995; Schulze, 2001; Kaminsky et al., 2004; Masun et al., 2004; Skinner et al., 2004). Note, however, that chemically similar spinel is found in a broad range of rocks, including mantle peridotite (e.g., Boyd et al., 1999; Lee and Rudnick, 1999); that is, these minerals "have no compositional characteristics permitting their assignment to a particular paragenesis" (Mitchell, 1995, p. 195). Magnesium-poor (mg# <0.25) Fe-Ti–rich compositions approaching the chromite-ulvöspinel/magnetite side of the spinel prism (orangeite group-B spinel of Mitchell, 1995) are absent in the rocks examined in the present study. Ilmenite is an important indicator mineral that exhibits paragenesis-dependent compositional characteristics. The compositions obtained in this study plot in the compositional field of picroilmenite from group-I kimberlite, and are distinct from ilmenite in group-II rocks in containing much lower Mn and Nb contents (Mitchell, 1995; Kaminsky et al., 2004).

The whole-rock geochemistry of the Wekusko Lake samples is, perhaps, most difficult to reconcile with the identification of these rocks as kimberlite. None of the fresh kimberlite analyses reported in the literature approach the major-element composition of the two studied samples. Using the whole-rock chemistry as the primary classification criterion, the rocks in question should be termed magnesiocarbonatite (Le Maitre, 2002, p. 10). A comparison of trace-element abundances sheds further light on the identity of the Wekusko Lake rocks. Although their V, Cr, Co, Ni, Sr, Ba, Nb, Zr and REE abundances are similar to those of group-I and group-II kimberlite, they contain significantly lower levels of Sc, Th and U, and have lower Zr/Hf and Nb/Ta ratios (typically, <45 and 20, respectively), relative to the values reported in the present study (e.g., Mitchell, 1995; O'Brien and Tyni, 1999; Kaminsky et al., 2004; Nowicki et al., 2004). The strong Ti anomaly (Figure GS-5-5) is also atypical of kimberlite (e.g., Mitchell, 1995; O'Brien and Tyni, 1999; Price et al., 2000). Further comparison demonstrates close similarity between the 'incompatible' trace-element budget of samples EPV-12A-94 and GBO-16 and the 'average carbonatite' (Figure GS-5-5). In common with the Wekusko Lake rocks, carbonatite shows superchondritic Nb/Ta and Zr/Hf, but primitive Y/Ho values, which has important implications for the interpretation of carbonatite petrogenesis (Chakhmouradian, 2006; A. Chakhmouradian, work in progress, 2006). Although the Cr, Co and Ni abundances are significantly lower in the 'average carbonatite' (39, 16 and 29 ppm, respectively; Chakhmouradian, unpublished data) than the present samples, (silico)carbonatite with comparable levels of compatible trace elements has been described in the literature (e.g., Bagdasarov, 1981; Stoppa and Woolley, 1997; Ripp et al., 2006). It is important to note that such carbonatite rocks are not associated with any alkaline silicate rocks and are believed to have formed directly from mantle-derived carbonatitic melts.

Thus, the Cr, Co and Ni enrichment of the Wekusko Lake rocks can be explained by the entrainment of mantle-derived xenocrysts (magnesian aluminous chromite and magnesian ilmenite) in ascending carbonatitic magma. The essentially dolomitic makeup of these rocks is consistent with the composition of carbonate melts in equilibrium with upper-mantle peridotite (Wallace and Green, 1988; Sweeney, 1994). Spinel and ilmenite xenocrysts of composition similar to those described in this report have been documented in kimberlite and other mantle-derived silica-undersaturated rocks (e.g., Boyd et al., 1999; Hearn, 1999; Lee and Rudnick, 1999; Grégoire et al., 2002; Aulbach et al., 2004).

Mica compositions from the Wekusko Lake samples are distinct from typical mantle phlogopite in their higher Fe and Mn, but lower Cr content. Mica from metasomatized peridotite in both on- and off-craton settings spans a wide range of compositions, but normally has mg# >84, MnO <0.1 wt. % and Cr_2O_3 >0.1 wt. % (Dawson, 1999; Lee and Rudnick, 1999; Moine et al., 2001; van Achterberg et al., 2001; Grégoire et al., 2002). The macrocrysts analyzed in the present work plot in the mg# and Al_2O_3 range of carbonatitic mica and contain comparable levels of Ti, Mn, Na and Ba (e.g., Seifert et al., 2000; Chakhmouradian and Zaitsev, 2002; Zaitsev et al., 2004). It is noteworthy that evolved Al-deficient mica transitional to tetra-ferriphlogopite $[K(Mg,Fe)_3(FeSi_3O_{10})(OH,F)_2]$ was not observed in the Wekusko Lake rocks. The minor-element chemistry of dolomite (Fe, Mn, Sr) and fluorapatite (Sr, REE) from samples EPV-12A-94 and GBO-16 is also consistent with a carbonatitic origin (e.g., Dawson et al., 1996; Seifert et al., 2000; Dawson and Hinton, 2003; Zaitsev et al., 2004).

Economic considerations

Accurate petrographic characterization of the Wekusko Lake rocks is primarily crucial for determining the nature and extent of melting in the underlying mantle and secondarily for evaluating the economic potential of this specific rock suite. The assessment of this region's diamond potential requires constraining such parameters as the depth of magma generation, the composition of mantle source(s) involved in the melting and the degree of melting. In common with kimberlite, carbonatitic magmas can potentially transport diamonds from the mantle. The alleged incompatibility of elemental and oxidized carbon is a misconception: diamond readily forms in natural and synthetic carbonate systems (e.g., Litvin et al., 2001; Pal'yanov et al., 2002; Shatsky et al., 2005). Both graphite and carbonate minerals can serve as the source of carbon for the nucleation and growth of diamonds at pressures in excess of 6 GPa (ca. 180 km depth).

In the absence of diamond-count data, the chemistry of indicator minerals and, to some extent, whole-rock geochemistry can be used for the assessment of diamond potential. Spinel macrocrysts of composition identical to the cores of the Wekusko Lake macrocrysts have been recovered from diamondiferous kimberlite in many areas around the world, including the Kaapvaal craton, Buffalo Hills and Attawapiskat kimberlite fields (Kong et al., 1999; Schulze, 2001; Hood and McCandless, 2004). The most Cr-rich compositions (55.1–55.6 wt. % Cr_2O_3) plot just outside the diamond-inclusion field of Gurney and Zweistra (1995). The enrichment of macrocryst cores in Al ([Cr/(Cr+Al] = 0.6–0.8) and variations in Mg, Al and Ti contents observed in some of the grains indicate metasomatic processes in the mantle source (Schulze, 2001), which is in agreement with the trace-element geochemistry of the Wekusko Lake rocks (see above). Mantle metasomatism (by carbonate-rich melts or fluids) has been recognized as a potential driving force behind diamond formation in the mantle (e.g., Navon, 1999; Cartigny et al., 2004). The largely dolomitic composition and K-Rb-Ba-depleted trace-element signature of the examined material indicate very low degrees of melting and the retention of refractory phlogopite in the source. It is not inconceivable that the most Mg-rich phlogopite macrocrysts (mg# = 0.80–0.85), also showing the lowest Al and Mn contents, may represent xenocrystic material. Unfortunately, the relationship between the chemistry of xenocrystic mica and diamond potential has not been studied in adequate detail.

The compositions of magnesian ilmenite plot in the upper middle part of the well-defined kimberlitic trend and well away from the reference curve for 'non-kimberlitic' ilmenite (Wyatt et al., 2004). It is noteworthy that, although ilmenite compositions from some alnöitic rocks straddle the reference curve (Wyatt et al., 2004), few of them contain as much MgO and Cr_2O_3 as the ilmenite macrocrysts examined in this study. The low Fe_2O_3 values of the Wekusko Lake ilmenite indicate relatively reducing (and therefore 'diamond-friendly') crystallization conditions.

The absence of garnet and other indicator minerals in the examined samples (cf. Gurney and Zweistra, 2003) makes further assessment of the economic potential of the Wekusko Lake rocks difficult. Additional information about the sources and processes involved in the petrogenesis of these rocks can be extracted from trace-element and isotopic data (see below).

Further work

A more detailed petrogenetic interpretation of the Wekusko Lake suite of 'kimberlitic dikes' will require the analysis of whole-rock and single-crystal isotope data. The stable-isotope (C, O) and radiogenic-isotope (Nd, Sr, Pb) compositions of these rocks will be used to determine the nature of their mantle source and the extent to which this primary isotopic signature was modified by magma evolution in the crust. The C-O isotope composition of carbonate minerals is sensitive to fractionation and degassing processes in the magma, as well as interaction of the magma with crustal materials (e.g., Bell and Rukhlov, 2004; Demény et al., 2004). The whole-rock radiogenic-isotope data have been successfully used for constraining the mantle sources of carbonatites and kimberlites, and the nature of processes that generate carbonatitic and kimberlitic melts in the mantle (e.g., Harmer, 1999; Bell and Rukhlov, 2004). The age of the Wekusko Lake rocks will be determined by combining single-mineral (U-Pb on zircon and Rb-Sr on phlogopite) and whole-rock geochronology. In order to aid diamond-exploration efforts in the region, the mineral-chemistry database for the Wekusko Lake rocks will be expanded and compared with the data for locally derived indicator minerals.

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GS-6

Activities of the Manitoba Geological Survey's Flin Flon regional office

by T.H. Heine

Heine, T.H. 2006: Activities of the Manitoba Geological Survey's Flin Flon regional office; *in* Report of Activities 2006, Manitoba Science, Technology, Energy and Mines, Manitoba Geological Survey, p. 63–64.

Summary

The Flin Flon office continued to provide technical and regulatory assistance to the mining and mineral-exploration communities in northwestern Manitoba. These activities include

- recording new mineral claims and accepting applications and submissions required under *The Mines and Minerals Act*,
- answering inquiries related to claim status and *The Mines and Minerals Act*, and
- maintaining a collection of current claim and land-status maps for the Province of Manitoba.

The office staff includes the Regional Geologist (Thomas H. Heine), Resident Geologist (David E. Prouse), Deputy Mining Recorder (Tana A. White) and a Claims Inspector (Dale Wride).

Mining recording functions

The Flin Flon Mining-Recording Office provides all services for registering claims and accepting submissions required under the terms of *The Mines and Minerals Act*. Claim history and status reports are prepared for clients on request. Clients are also shown how to use the Manitoba Science, Technology, Energy and Mines Web portal.

Exploration assistance

One of the main functions of this office is to provide assistance to companies and individuals involved in mineral exploration and development in the region. This consists of locating information, providing technical advice and making site visits to client offices and their properties. The Centennial core viewing facility is maintained as a convenient location where drillcore can be temporarily stored and logged in a heated facility. A field camp used for summer projects is also maintained at this site.

This office continued to provide technical support for the Green Project (Heine, 2005), where additional funding allowed it to continue for another year. This community-based project has been successfully treating areas affected by acidic emissions from the Flin Flon smelter with finely crushed dolomitic limestone. The annual reports and results of this project can be seen on their web site at www.greenproject.ca.

Meetings of the Manitoba–Saskatchewan Prospectors and Developers Association were attended in order to keep track of issues related to provincial policies and regulations.

Considerable interest has recently been shown in the Sherridon area. One company has assembled a significant land package and is undertaking an extensive exploration program. As part of this effort, the company has offered to co-operate with the upcoming TGI 3 initiative that is being co-ordinated with the Geological Survey of Canada. Full assistance is being provided by the Flin Flon office and the Manitoba Geological Survey to facilitate base- and precious-metals exploration in this area.

The development of a digital Manitoba Mineral Deposits database is advancing. The progress of this project is described in detail elsewhere in this volume (Heine, GS-26, this volume).

Economic considerations

Because of its location in the centre of Manitoba's base-metal mining district, the Flin Flon regional office is able to handle regulatory and technical requests efficiently and maintain continuous contact with the stakeholders of the region.

Contact information

Flin Flon regional office staff can be contacted at the following location:

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Dale Wride	Telephone: (204) 687-1635 Email: dwride@gov.mb.ca

Manitoba Mineral Resources Division Web portal: www.gov.mb.ca/minerals

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Heine, T.H. 2005: Activities of the Manitoba Geological Survey's Flin Flon regional office; *in* Report of Activities 2005, Manitoba Industry, Economic Development and Mines, Manitoba Geological Survey, p. 30–31.

GS-7 Preliminary results from geological mapping of the Bear Lake greenstone belt, Manitoba (parts of NTS 53M4 and 63P1)

by R.P. Hartlaub[1] and C.O. Böhm

Hartlaub, R.P. and Böhm, C.O. 2006: Preliminary results from geological mapping of the Bear Lake greenstone belt, Manitoba (parts of NTS 53M4 and 63P1); *in* Report of Activities 2006, Manitoba Science, Technology, Energy and Mines, Manitoba Geological Survey, p. 65–73.

Summary

The Bear Lake area, lying within the Superior Province in Manitoba, hosts several shear zone–bounded panels of lower- to middle-amphibolite facies, mixed volcanic and sedimentary rocks. Together, these panels make up the discontinuously exposed Bear Lake greenstone belt. The belt likely represents the westerly, strongly attenuated continuation of the Oxford Lake–Knee Lake belt, the largest contiguous greenstone belt in the northwestern Superior Province. The volcanosedimentary package at Bear Lake is most comparable to supracrustal rocks of the Hayes River Group at northern Oxford Lake and southwestern Knee Lake, but may also contain rocks of the Oxford Lake Group. At Bear Lake, the supracrustal rocks are interpreted as mafic, intermediate and felsic volcanic rocks, volcanic breccia, iron formation, conglomerate, volcaniclastic rocks and greywacke. Shear zones bounding the Bear Lake greenstone belt are east trending, contain dextral kinematic indicators and include a major northwest-southeast splay. Granite-granodiorite locally cuts the greenstone belt and makes up the majority of outcrop on the eastern half of Bear Lake. Together with planned mapping in the Utik Lake area, this study will provide an improved geological context and regional framework for base- and precious-metal exploration in this part of the northern Superior Province.

Introduction

The gold and base-metal potential of Precambrian belts of volcanic rock, also known as greenstone belts, has been well established. Within the Archean Superior Province of Manitoba and Ontario, numerous Cu- and Zn-rich, volcanic-associated massive sulphide (VMS) deposits have been discovered in these greenstone belts (Evans and Moon, 1995). Where shear zones intersect belts of volcanic and sedimentary rock, there is also significant potential for orogenic gold mineralization (e.g., Lin, 2001; Dubé et al., 2004). The strong economic potential of these belts is the impetus for a new three-year effort to re-examine the volcanic and sedimentary rocks in the Utik and Bear lakes area of the northern Superior Province in Manitoba. During the first year of the project, the Bear Lake area was remapped at 1:50 000 scale. The preliminary findings of the fieldwork at Bear Lake are summarized in this report and on a preliminary geological map (Böhm and Hartlaub, 2006). The plan for 2007 is to remap the Utik Lake area and subsequently synthesize the field and analytical results, with final geological maps of the two areas being produced in 2008.

Bear Lake is located approximately 125 km southeast of Thompson, Manitoba, in the Archean Superior Province. The lack of road access has limited the amount of geological and exploration work in the area, but previous geologists (Milligan, 1952; Allen, 1953; Milligan and Take, 1954; Weber, 1974) have noted well-exposed volcanic and volcanogenic rocks in the area. Volcanic and sedimentary rocks that are possibly coeval with those at Bear Lake are also exposed 10 km to the north at Utik Lake (Hargreaves, 1975; Hargreaves and Ayres, 1979). The volcanic sequences, informally termed the Bear Lake and the Utik Lake greenstone belts, lie along the northern margin of the Gods Lake Domain (Weber and Scoates, 1978), which is now referred to as the Oxford Lake–Stull Lake terrane (Skulski et al., 2000) and is located south of the granulite-grade Pikwitonei Domain.

The Bear Lake and Utik Lake supracrustal belts have an easterly trend that parallels the regional (Card, 1990) structure of the Superior Province. Based on regional correlation using magnetic data and field lithological descriptions, the Bear Lake greenstone belt likely forms the westerly continuation of the Oxford Lake–Knee Lake belt (Figure GS-7-1). At Knee Lake, this largest greenstone belt in the northwestern Superior Province represents a complex of two supracrustal sequences, the volcanic-dominated, ca. 2.83 Ga Hayes River Group and the sedimentary-dominated, ca. 2.71 Ga Oxford Lake Group (e.g., Syme et al., 1997; Corkery et al., 1999). Dating of the volcanic rocks at Bear Lake is one of the main focuses of this study and will, together with detailed major- and trace-element geochemistry and isotope geochemistry, facilitate correlation with other dated supracrustal rocks in the region. The volcanic and sedimentary rocks at Bear Lake are intruded by voluminous granite and granodiorite gneiss exposed in the region. A thin veneer of glacial material covers much of the area,

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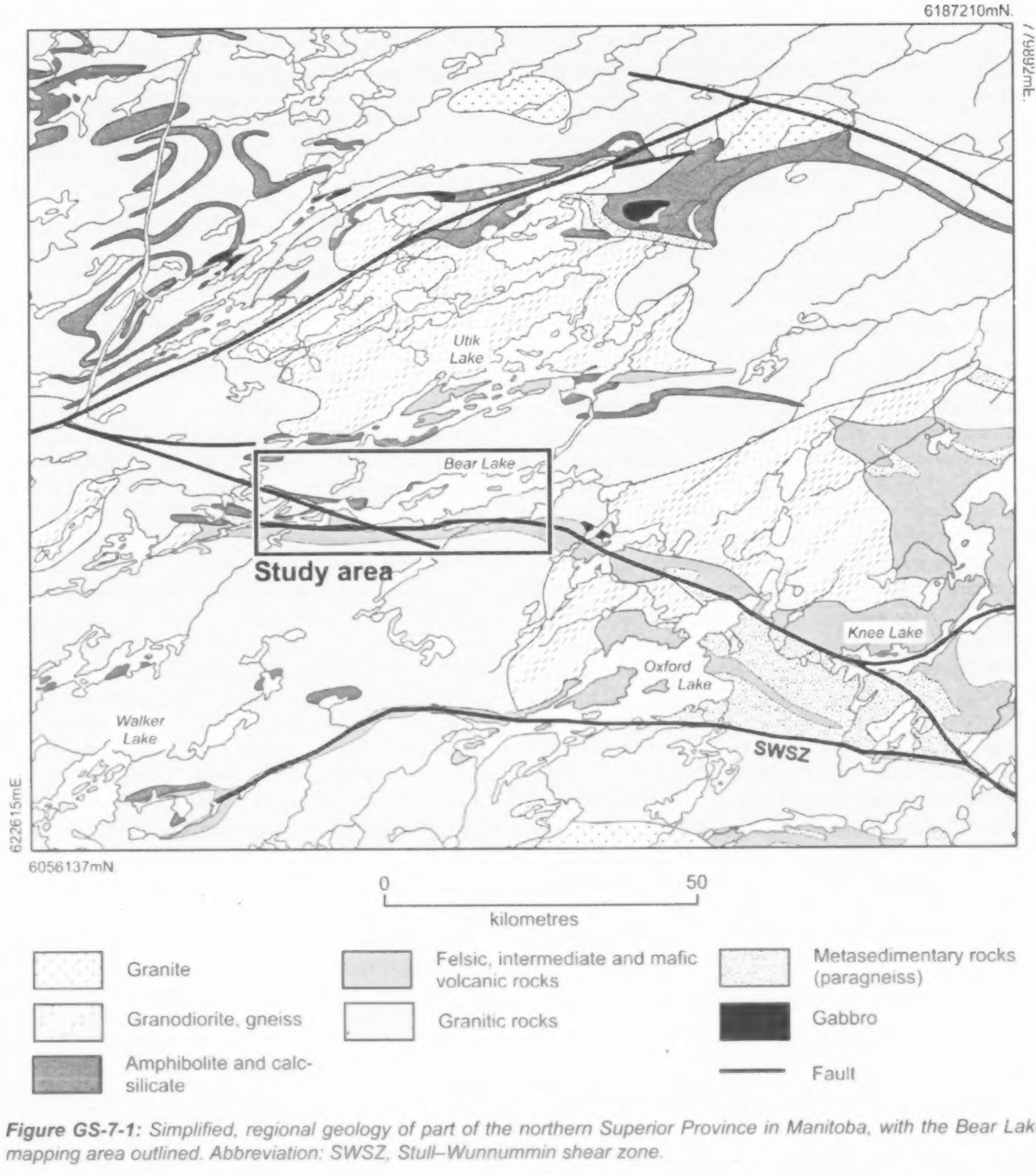
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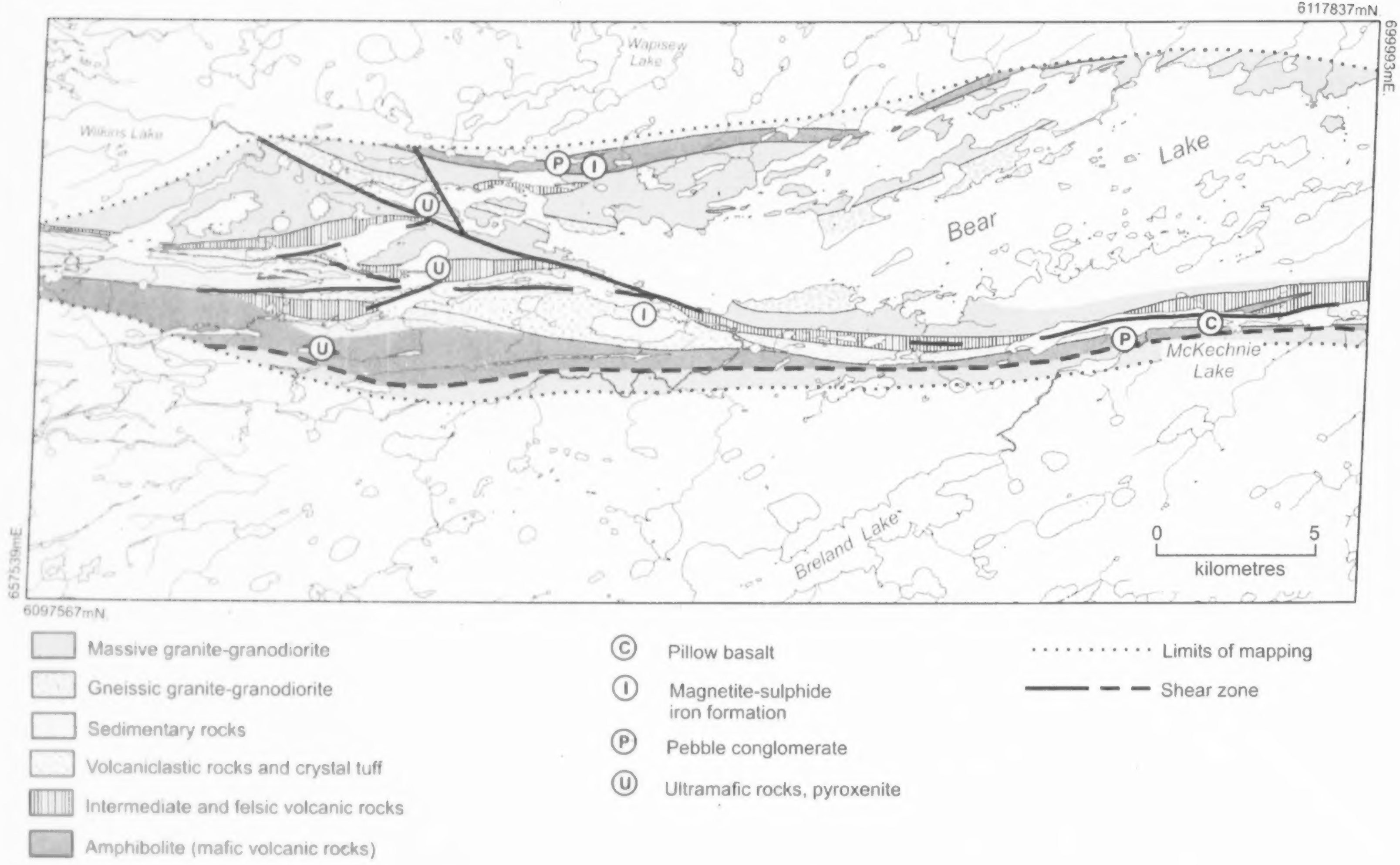
779892mE.
Utik Lake
Bear Lake
Study area
Knee Lake
Oxford Lake
Walker Lake
SWSZ
622615mE
6056137mN
0
50
kilometres
Granite
Granodiorite, gneiss
Amphibolite and calc-silicate
Felsic, intermediate and mafic volcanic rocks
Granitic rocks
Metasedimentary rocks (paragneiss)
Gabbro
Fault

Figure GS-7-1: *Simplified, regional geology of part of the northern Superior Province in Manitoba, with the Bear Lake mapping area outlined. Abbreviation: SWSZ, Stull–Wunnummin shear zone.*

but this overburden is relatively thin on western Bear Lake.

General geology

Two main east-trending structural panels of sedimentary and volcanic rocks occur within the Bear Lake area. One panel is exposed along the northwestern end of Bear Lake and a second, thicker one occurs at southwestern Bear Lake and extends east to McKechnie Lake (Figure GS-7-2). The northwest-trending shear zone that cuts across western Bear Lake acts as the northern boundary of the southern panel. Rocks interpreted to be volcanic at Bear Lake include mafic, intermediate and felsic compositions, volcanic breccia, and volcaniclastic and tuffaceous rocks. Rare horizons of sulphide-facies iron formation are interlayered with these presumably volcanic and volcaniclastic rocks. Clastic sedimentary rocks of unclear relative age and association with the volcanic rocks include minor greywacke and pebble conglomerate. Graded bedding indicates mainly that the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kilometres
Massive granite-granodiorite
Gneissic granite-granodiorite
Sedimentary rocks
Volcaniclastic rocks and crystal tuff
Intermediate and felsic volcanic rocks
Amphibolite (mafic volcanic rocks)
C Pillow basalt
I Magnetite-sulphide iron formation
P Pebble conglomerate
U Ultramafic rocks, pyroxenite
Limits of mapping
Shear zone

Figure GS-7-2*: Simplified geological map of the Bear Lake area.*

volcanic and sedimentary rocks consistently young to the south. The consistent south-dipping foliation and south younging direction indicate that no significant refolding of the greenstone belt has occurred. The two structural panels are partially bounded by shear zones, as well as by large volumes of granite and granodiorite gneiss (Figure GS-7-2). These felsic intrusive rocks clearly crosscut the mafic volcanic rocks in many locations and were therefore sampled for U-Pb geochronology to obtain a minimum age for volcanism. The youngest units in the area are undeformed granite, pegmatite and mafic dikes.

Supracrustal rocks

Amphibolite interpreted as mafic volcanic rocks

Black, fine- to medium-grained amphibolite is the dominant mafic rock type in both structural panels. Amphibolite occurs as massive, pillowed and layered varieties, with the massive variety the most abundant. Obviously pillowed amphibolite has been observed at two localities in the map area. Well-developed volcanic pillows, with amphibole- and garnet-rich selvages, occur at one location in the northern panel (Figure GS-7-3a, -3b). A second location was observed on McKechnie Lake. Larger exposures of pillowed basalt have been well described by Hargreaves and Ayres (1979) for a location 10 km northwest on Utik Lake. The authors interpret the common compositional layering in amphibolite exposures elsewhere in the map area as possibly representing highly flattened pillow structures. The origin of the massive amphibolite is less certain, but the local presence of pillows and their sheared equivalents suggests that the massive amphibolite may also be derived from mafic flows.

Amphibolite is locally interlayered with rocks interpreted to be intermediate and felsic volcanic and sedimentary rocks. Most of the examined amphibolite exposures contain trace pyrite, with rusty layers, locally containing abundant pyrite and pyrrhotite, along the contact between amphibolite and felsic and intermediate rocks. Epidotization of sheared or boudinaged calcsilicate layers in amphibolite is common.

Pyroxenite and ultramafic schist

Ultramafic rocks were identified at several locations on western Bear Lake. Medium- to coarse-grained, equigranular, massive to weakly foliated pyroxenite and hornblendite, which are closely associated with strongly sulphidic amphibolite interpreted as mafic volcanic rock, form several small exposures south of Mahigan River in the southwestern part of the area (Figure GS-7-2). In addition, one exposure of decimetre-sized rafts of altered pyroxenite within pegmatitic leucogranite was found at the northwest arm of Bear Lake. At west-central Bear Lake, a dark green, dense, altered amphibole- and chlorite-rich schist is interlayered with presumably intermediate volcanic rocks. This schist likely represents a hydrated and metamorphosed ultramafic extrusive rock or sill.

Felsic and intermediate rocks interpreted as volcanic rocks

Fine-grained, medium grey, compositionally layered intermediate rocks, interpreted to be volcanic, make up less than 20% of the greenstone belt at Bear Lake. These rocks are typically plagioclase±biotite-phyric and interlayered with amphibolite or rocks interpreted to be volcaniclastic.

Several thin units of felsic, quartz-feldspar-phyric rock were identified in the map area, with some of the best exposed layers located south of Bear Lake on the Piskominahikoska River (Figure GS-7-2). In this area, several 5 to 10 m thick sheets of white aphanitic felsic rock of rhyolite to rhyodacite composition are interlayered with amphibolite. These felsic rocks are locally porphyritic, with up to 30% highly attenuated plagioclase and/or quartz phenocrysts that are moderately to highly flattened (Figure GS-7-3d). A single plagioclase-phyric felsic dike that cuts tuffaceous rocks may represent a feeder to this unit.

Felsic to intermediate fragmental rock interpreted as volcanic breccia is well exposed at one location on the Piskominahikoska River (Figure GS-7-3e, -3f), and several other highly deformed breccias of probable volcanic origin were also identified. The volcanic breccia is composed of felsic and intermediate clasts in an aphanitic, light grey, felsic groundmass. Clasts are angular, 2 to 20 cm in length and texturally fine grained to aphanitic with rare plagioclase phenocrysts.

Magnetite-sulphide iron formation

Magnetite-sulphide iron formation is fine to medium grained, well layered to laminated and forms thin (1–5 cm) horizons within volcanic and volcaniclastic rocks (Figure GS-7-4a). Fine-grained pyrite is the dominant mineral in these layers and, where weathered, the rock has a brown gossanous appearance. Chert was not noted in this unit. The intercalated nature of magnetite-sulphide iron formation with presumably volcanic rocks is consistent with a proximal volcanic source for the contained metals and sulphides. Although the iron formation may be related to hydrothermal activity, no significant alteration was identified in the surrounding rocks.

Possible volcaniclastic rocks and crystal tuff

One of the most abundant units within the Bear Lake map area is a mixed package of rocks interpreted as volcanogenic sandstone and tuffaceous rocks. The terms tuff and tuffaceous are used here in a descriptive and nongenetic sense, following the granulometric classification of volcanic rocks proposed by Fisher (1966). The

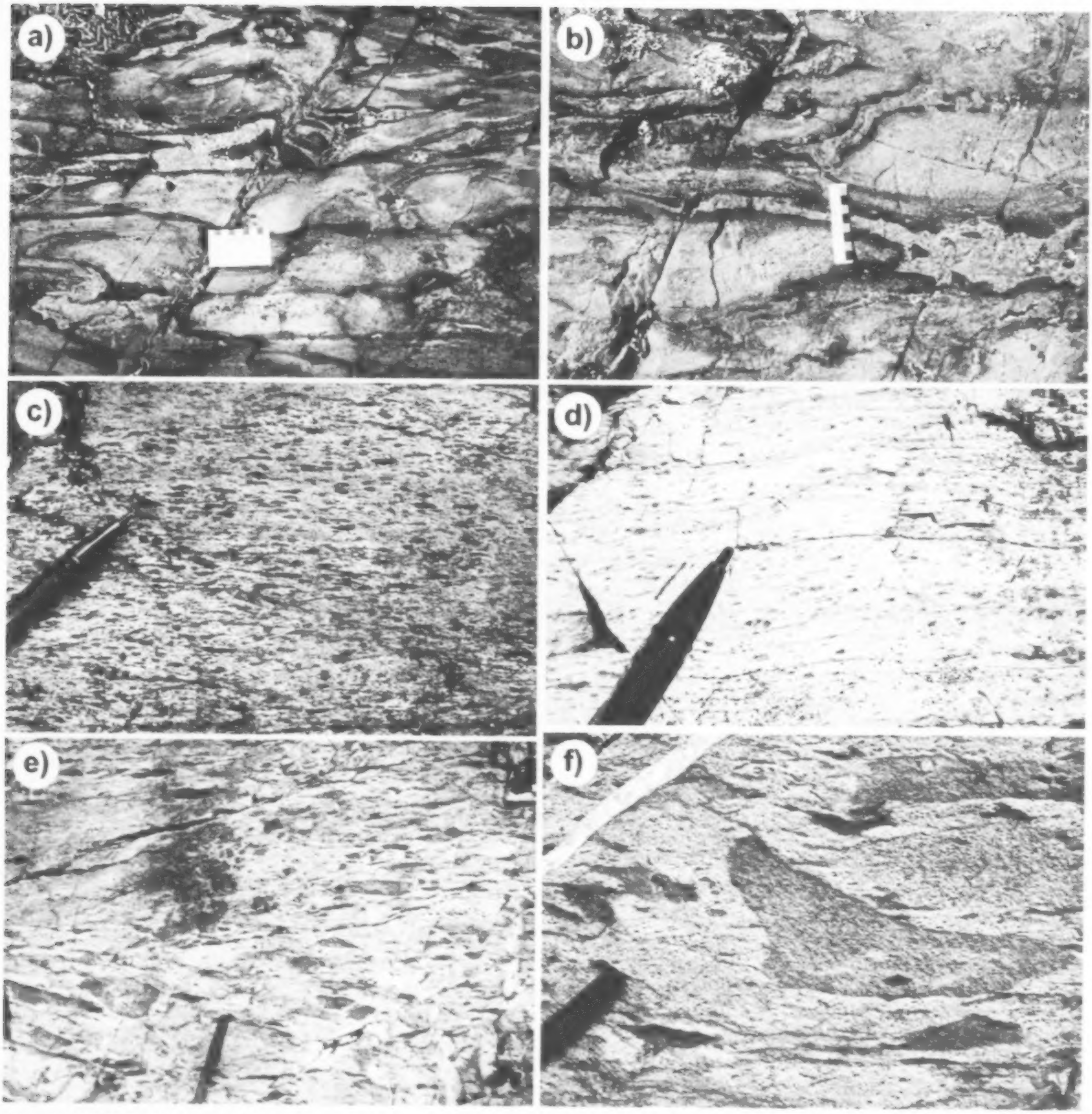

***Figure GS-7-3:** Archean volcanic rocks of the Bear Lake area: **a)** metamorphosed pillows in amphibolite (station 97-06-552, UTM Zone 14, 673914E, 6112172N [NAD 83]); **b)** pillowed mafic flow; note the dark garnet- and hornblende-rich pillow selvages (station 97-06-552, UTM 673914E, 6112172N); **c)** intermediate volcanic rock with flattened hornblende phenocrysts (station 97-06-648, UTM 669257E, 6108574N); **d)** quartz-phyric felsic volcanic rock (station 97-06-685, UTM 679734E, 6106179N); **e)** volcanic breccia (station 97-06-683, UTM 679837E, 6107019N); **f)** close-up of volcanic breccia with moderately flattened clasts (station 97-06-683, UTM 679837E, 6107019N).*

clastic sedimentary rocks at Bear Lake are locally interbedded with rocks interpreted as crystal-rich tuff and felsic to intermediate volcanic rocks. The grain size of the sedimentary rocks ranges from sand to silt; graded bedding identified at numerous locations (Figure GS-7-4b) consistently indicates a southward younging direction. Interlayering of coarse sandy layers and fine silty argillite and/or tuffaceous layers (Figure GS-7-4c) is especially well developed at the western end of Bear Lake near the Mahigan River (Figure GS-7-2). Where the argillitic deposits are thickest, the rock displays a strong fissility and cleaves into thin sheets.

Preliminary petrographic thin-section examination of rocks in this unit reveals that the contained phenocrysts are primarily monomineralic quartz and/or feldspar. Although large euhedral plagioclase crystals are locally

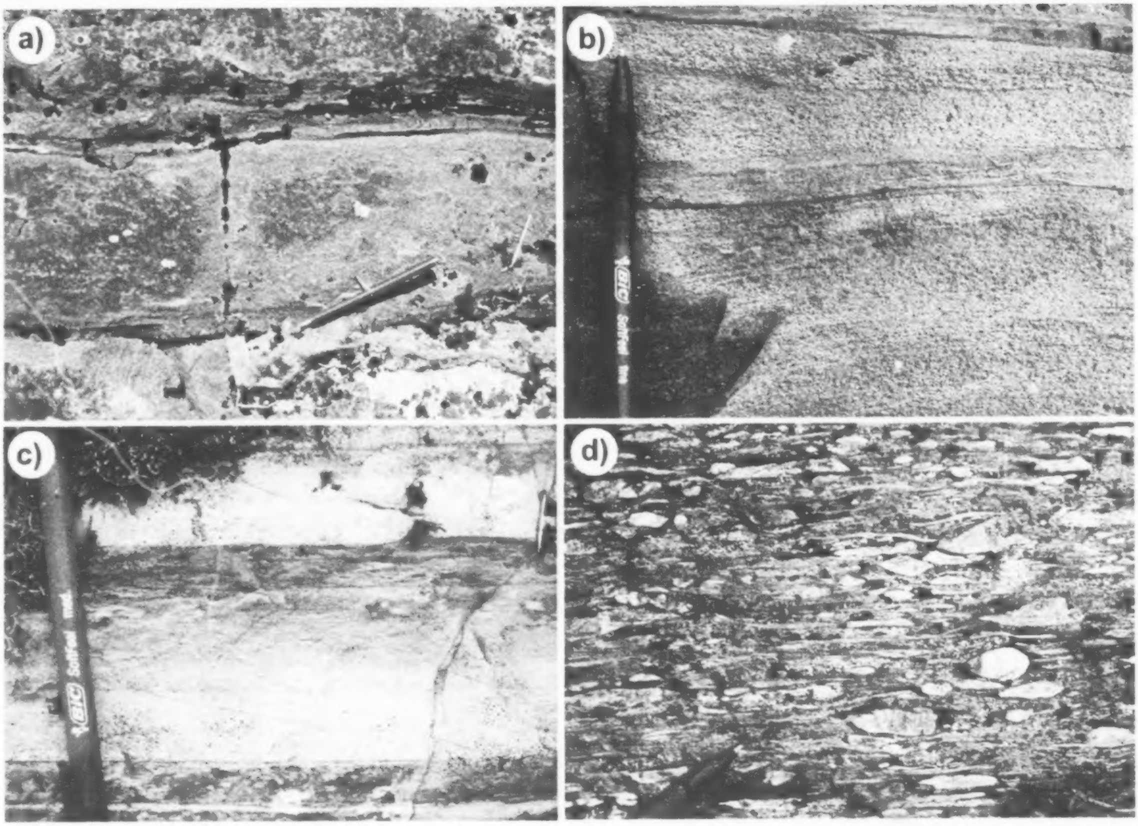

Figure GS-7-4: *Archean sedimentary rocks of the Bear Lake area:* ***a)*** *magnetite-sulphide iron formation interlayered with plagioclase-phyric felsic volcanic rocks (station 97-06-513, UTM Zone 14, 676874E, 6107574N [NAD 83]);* ***b)*** *graded bedding in volcanogenic sandstone, with younging toward the top of the photo (station 97-06-593, UTM 660057E, 6108595N);* ***c)*** *interlayering of volcanogenic sandstone and argillaceous (tuffaceous?) rock, with graded bedding indicating younging toward the top of the photo (station 97-06-652, UTM 669089E, 6107944N);* ***d)*** *pebble conglomerate from McKechnie Lake (station 97-06-209, UTM Zone 15, 311987E, 6107834N).*

well developed, the majority of grains in the volcanogenic sandstone are highly fragmented and angular.

Sedimentary rocks

Fine- to medium-grained, rusty-weathering greywacke contains 10 to 20% biotite±cordierite±sillimanite. Quartz-rich melt layers, which form up to 20% of outcrops, are common and up to a few centimetres wide. The main exposures of greywacke are north of the pillowed basalt at northwestern Bear Lake and form common interlayers, ranging from a centimetre to few decimetres wide, within felsic and intermediate tuff. Good examples of interbedding with felsic and intermediate tuff are exposed along the northern part of the Mahigan River system west of Bear Lake.

Pebble conglomerate interlayered with argillite is exposed along the southern shore of McKechnie Lake. Clasts are well rounded, highly flattened and lie within a sandstone matrix (Figure GS-7-4d). Clast length:width ratio ranges from 3:1 to 6:1. The average clast length is approximately 3 cm, with the largest clasts up to 10 cm. The predominant clast lithology is vein quartz, but quartz-phyric felsic and hornblende-phyric intermediate volcanic clasts were also identified. Flattening is more pronounced in the volcanic clasts as compared to the evidently more rigid quartz pebbles.

Intrusive rocks

Gneissic granite-granodiorite

Medium- to coarse-grained felsic intrusive rocks make up the majority of exposed bedrock in the eastern half of the Bear Lake area (Figure GS-7-2). Compositionally, these intrusive rocks are granite to granodiorite with an average of 10% biotite. Detailed petrographic analysis of this unit is included in Allen (1953). Hornblende, K-feldspar augen and pegmatitic patches are locally present. Granite-granodiorite ranges from moderately foliated to strongly gneissic and locally contains randomly oriented supracrustal xenoliths of mafic or intermediate composition. These xenoliths are likely derived from the

Bear Lake greenstone belt, as granite gneiss crosscuts amphibolite in several locations. Some outcrops display two main components: an older biotite-granodiorite gneiss and a younger anastomosing network of foliated leucogranite. Trains of angular mafic inclusions may represent dismembered dikes rather than wallrock. Many of the mafic layers have undergone dextral shear. Retrogression of mafic minerals and inclusions to chlorite±epidote is focused along late shears and fractures. Mylonitic granite with ribbon quartz, occurring within the major east- and northwest-trending shear zones, was sampled for U-Pb geochronology to obtain a maximum age constraint on these shear zones.

Massive granite

Coarse-grained, homogeneous, massive hornblende and/or biotite granite is exposed in parts of western and central Bear Lake (Figure GS-7-2). The granite is locally pegmatitic and contains no visible xenoliths, dikes or visible foliation, and is therefore assumed to be either Neoarchean post-tectonic (<2.68 Ga) or Paleoproterozoic (ca. 1.82–1.86 Ga) in age.

Gabbro dike

Gabbro dikes were identified in two exposures in the Bear Lake area. These northwest-trending dikes are fine to medium grained, straight sided, undeformed and up to 5 m thick. The dikes are brown weathering, contain >50% pyroxene and may be part of the ca. 1.88 Ga (Heaman et al., 1986) Molson dike swarm. This mafic magmatic event has been recorded all along the northwestern Superior Province margin, and is linked to nickel mineralization in the Thompson Nickel Belt (e.g., Hulbert et al., 2005).

Metamorphic and structural geology

The Bear Lake area appears to have reached lower to middle amphibolite facies metamorphic grade under moderate to low pressures. Mafic volcanic rocks (amphibolite) contain hornblende and garnet, and lack prograde chlorite. Sillimanite and cordierite were identified in initial petrographic analysis of greywacke from northwestern Bear Lake; there is, however, a general paucity of highly aluminous rock. A site originally identified by Weber (1974) to contain kyanite was re-examined and found to be located within a mixed zone of pegmatite that is likely related to the movement of high-pressure aluminous fluids rather than to regional conditions. This interpretation is supported by the presence of cordierite and weakly deformed pillowed volcanic rocks less than 1 km from the kyanite pegmatite. Rocks of the Bear Lake area have not reached minimum melt pressure and temperature conditions.

The main foliation in the Bear Lake area trends east and is steeply south dipping. Granite-granodiorite locally contains a second foliation that commonly strikes northwest, parallel to the northwest-trending, dextral shear zone that transects Bear Lake. This northwest-trending shear zone is considered to be a splay off the main east-west system of regional shear zones. Mylonitic rocks are best developed in the east-trending shear zones that run along southwestern Bear Lake. These mylonitic rocks range from moderately porphyroclastic gneiss to very fine grained recrystallized ultramylonite. Stretching lineations are generally not present or preserved. Overall, the orientation of shear zones on Bear Lake (Figure GS-7-2) roughly mirrors that of the small-scale dextral shears noted at outcrop scale.

Except for locally present disharmonic z-folds, small-scale minor fold structures are rare in the Bear Lake area. The minor z-folds have close to tight interlimb angles and steeply south-dipping axial planes, and plunge shallowly to the east or west. The orientation of these z-folds is consistent with the dextral sense of regional shearing. The timing of deformation and metamorphism is uncertain, but the main metamorphism and flattening, as well as the regional shearing, predate intrusion of the undeformed granites and mafic dikes.

Economic considerations

The main economic potential in the Bear Lake area is for volcanic-associated massive sulphide (VMS) deposits and orogenic gold deposits, with some minor potential for epithermal and paleoplacer gold mineralization. Many volcanic-associated massive sulphide deposits occur within volcanic arcs, particularly those that have undergone extension (Cathles et al., 1983; Syme and Bailes, 1993; Syme et al., 1999). In addition, orogenic gold deposits in the northern Superior Province are known to be localized near or within major transpressive shear zone structures.

Potential for VMS deposits in the Bear Lake area resides in the supracrustal rocks of the greenstone belt, within rocks interpreted as subaqueous volcanic and volcaniclastic (e.g. Bernier and MacLean, 1989). The Bear Lake greenstone belt includes a mixed package of basalt and intermediate to felsic, presumably volcanic and volcaniclastic rocks, with the most prospective portions of the volcanic supracrustal sequence being felsic volcanic rocks that make up just 5 to 10% of this sequence. The local magnetite-sulphide iron formation and volcaniclastic sedimentary rocks interlayered with this package are of particular interest because they have associated sulphides. Volcanogenic conglomerates in the map area could also hold potential for paleoplacer gold mineralization.

The potential for volcanic-associated vein and shear-zone gold (e.g., Thorpe and Franklin, 1984) is likely to be highest along the east-trending high-strain zones (and locally developed, subparallel alteration zones) that cut the sedimentary and volcanic rocks at west Bear Lake. Subsidiary fault structures branching from regional shear zones are common sites of gold mineralization (Eisenlohr et al., 1989). The shear zones along southwestern Bear Lake are along strike from, and may form part of, a major splay of the Stull–Wunnummin Shear Zone that transects the northeastern portion of Oxford Lake (Fig. GS-7-1). The Stull–Wunnummin Shear Zone and splays originating from it are commonly the locus for gold mineralization in this part of the Superior Province. At southwestern Bear Lake, the northwest-trending splay of the generally east-trending shear zone is also dextral and therefore an extensional structure (dilational), making it favourable for focusing gold-bearing metamorphic fluids. Although gold-related alteration is of limited extent in the Bear Lake area, iron-carbonate-sericite-chlorite alteration in strongly fractured zones of dominantly felsic and intermediate tuffaceous rocks along parts of the south Mahigan River seems most prospective. Chemical analyses of samples of altered and less altered supracrustal rocks are pending.

In addition to previously explored exposures of mineralized and altered felsic volcanic rocks in the Bear Lake area (e.g., Assessment Files 94568 and 94580, Manitoba Science, Technology, Energy and Mines, Winnipeg), one of the best exposures of mineralized volcanic rocks was found along the Piskominahikoska River (Figure GS-7-2, UTM Zone 14, 673914E, 6112172N [NAD 83]).

Acknowledgments

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GS-8

New tectonostratigraphic framework for the northeastern Kisseynew Domain, Manitoba (parts of NTS 63O)

by J.A. Percival[1], H.V. Zwanzig and N. Rayner[1]

Percival, J.A., Zwanzig, H.V. and Rayner, N. 2006: New tectonostratigraphic framework for the northeastern Kisseynew Domain, Manitoba (parts of NTS 63O); *in* Report of Activities 2006, Manitoba Science, Technology, Energy and Mines, Manitoba Geological Survey, p. 74–84.

Summary

High-resolution images from the 2006 Wuskwatim Lake aeromagnetic survey were used in conjunction with new mapping and isotopic data to reinterpret the geology of the Kisseynew Domain (KD) west of the Thompson Nickel Belt (TNB). The results suggest that a 60 km wide zone, previously considered to consist entirely of Burntwood Group migmatite and younger granite, is structurally interleaved with heterogeneous orthogneiss and paragneiss resembling Superior Province basement and the lower part of its cover sequence (Ospwagan Group). These units are exposed in structural culminations suggesting a widespread distribution under a structural cover of the Burntwood Group in the northeastern KD. Iron formations that form aeromagnetic markers may correspond to similar units within the Pipe Formation, making parts of the region prospective for Thompson-type nickel mineralization.

Introduction

As part of the Flin Flon project of the Targeted Geoscience Initiative III Program, a field program was initiated to examine possible westward extensions of Thompson Nickel Belt strata in the northeastern Kisseynew Domain (Figure GS-8-1). The study was prompted by drillcore data provided by Inco Limited and New Insco Mines (now Nuinsco Resources Ltd.) from a nickel-sulphide orebody hosted in the Ospwagan Group in the Mel zone, 10 km west of the exposed Superior Province margin (Zwanzig and Böhm, 2002, 2004); and in the Wuskwatim Lake area to the southwest, by data from a new high-resolution aeromagnetic survey (Coyle and Kiss, 2006) and recent Sm-Nd isotopic data that indicate >3 Ga ages for plutonic and supracrustal units (Percival et al., 2005). Together, these observations have suggested the possible existence of Ospwagan Group inliers up to 60 km west of the Superior margin within an area dominated by Burntwood Group metasedimentary rocks and granitoid rocks characterized by juvenile Nd isotopic signatures. The presence of such inliers would extend the area for nickel exploration in Manitoba because all significant deposits in the main part of the TNB are hosted by the Paleoproterozoic Ospwagan Group, which lies unconformably on Neo- to Paleoarchean basement gneiss.

This report provides a revised tectonic framework and structural interpretation based on the results from local remapping in the northeastern part of Kisseynew Domain (KD) in July 2006 (Zwanzig et al., GS-9, this volume; Growdon et al., GS-10, this volume). The results broadly support the presence of TNB crust: they are consistent with the presence of Archean orthogneiss (possibly TNB basement) and confirm that associated paragneiss consists primarily of Archean detritus. Preliminary stratigraphy, geochemistry and new Nd isotope data of the newly mapped assemblages compiled in a companion paper (Zwanzig et al., GS-9, this volume) indicate that a first-order correlation between the paragneiss sequence and the Ospwagan Group in the main part of the TNB is probable.

Access to the region is by fixed-wing aircraft to water bodies including the Burntwood River. Exposure is sparse and limited to low shoreline outcrops best viewed at low water conditions. Water levels were at historical highs during the 2006 field season, limiting both the quality and quantity of exposures.

Tectonic elements

Basement-type orthogneiss

Orthogneiss is exposed in the core of several structural windows: at Wuskwatim Lake, a few kilometres to the northwest on the Burntwood River and at Tullibee Lake (Figures GS-8-1 and GS-8-2a, 2b). A diffuse, oval (3 by 12 km) positive aeromagnetic anomaly (Coyle and Kiss, 2006; Zwanzig et al., 2006b) arises from the Wuskwatim Lake occurrence. Outcrops on islands in central Wuskwatim Lake consist dominantly of foliated to gneissic tonalite with characteristic orthopyroxene-biotite assemblages. Sporadic enclaves of garnet-orthopyroxene-hornblende-biotite paragneiss and ortho-pyroxene-clinopyroxene-hornblende-plagioclase metabasite constitute less than 5% of the exposed bedrock. In one location, metabasite with rusty-weathering patches grades to a layered sedimentary or volcaniclastic unit (Figure GS-8-2c), suggestive of supracrustal origin. Other more massive pyroxene-bearing metabasite bodies transect gneissic layering and

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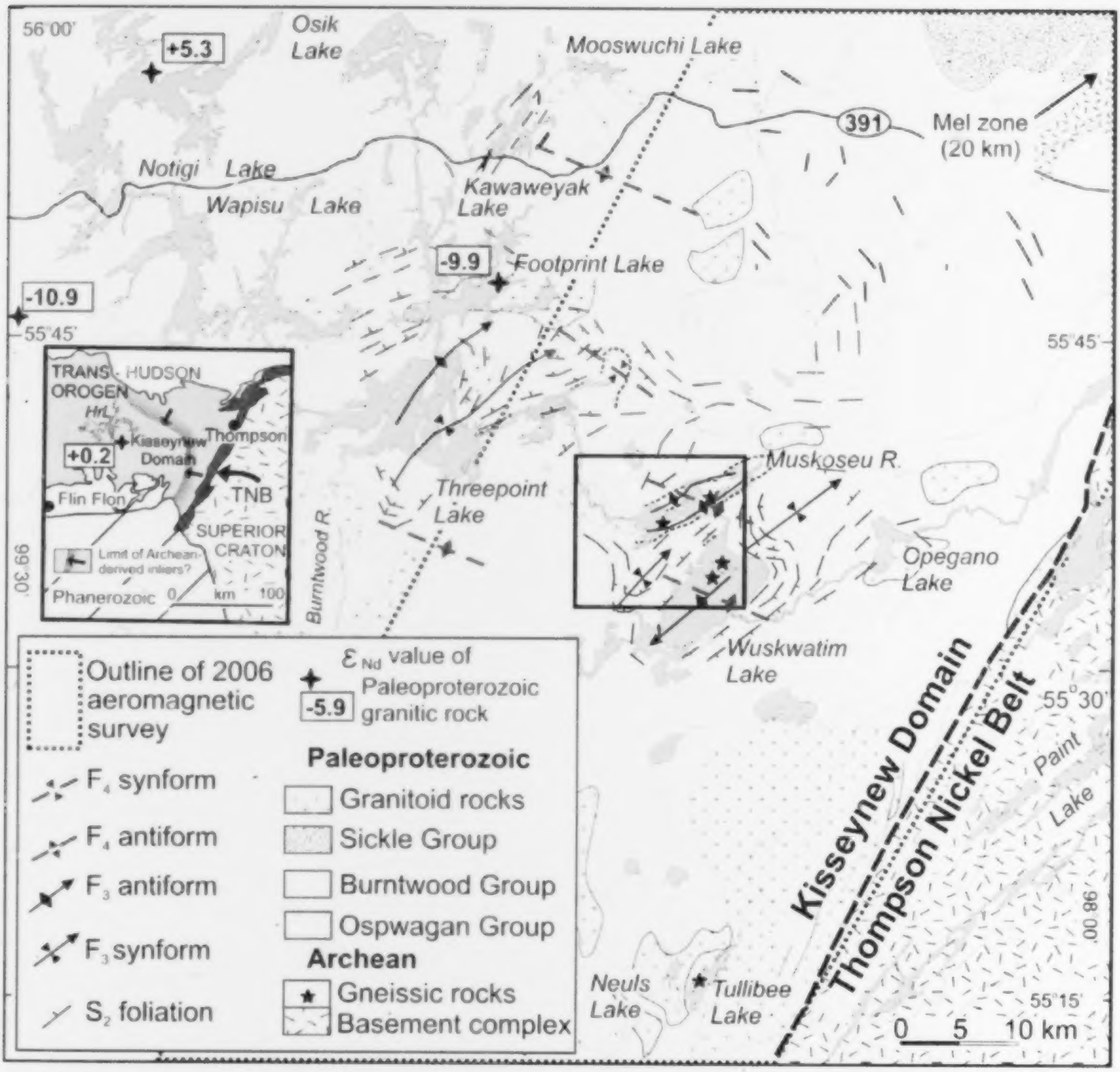
56°00'
+5.3
Osik Lake
Mooswuchi Lake
391
Mel zone (20 km)
Notigi Lake
Wapisu Lake
Kawaweyak Lake
-9.9
Footprint Lake
-10.9
55°45'
55°45'
TRANS-HUDSON OROGEN
HrL
+0.2
Kisseynew Domain
Thompson
Flin Flon
TNB
SUPERIOR CRATON
Limit of Archean-derived inliers?
Phanerozoic
0 km 100
99°30'
Burntwood R.
Threepoint Lake
Muskoseu R.
Opegano Lake
Wuskwatim Lake
Outline of 2006 aeromagnetic survey
F4 synform
F4 antiform
F3 antiform
F3 synform
S2 foliation
ε Nd value of Paleoproterozoic granitic rock
-5.9
Paleoproterozoic
Granitoid rocks
Sickle Group
Burntwood Group
Ospwagan Group
Archean
Gneissic rocks
Basement complex
Kisseynew Domain
Thompson Nickel Belt
55°30'
Paint Lake
98°00'
Neuls Lake
Tullibee Lake
55°15'
0 5 10 km

Figure GS-8-1: *Location map showing features referred to in the text. Outlined area near Wuskwatim Lake shows the location of Figure GS-8-4. Inset map shows the possible distribution of Archean crust beneath the northeastern Kisseynew Domain and the locations of Highrock Lake (HrL) and sample 25-72-4030.*

are clearly intrusive. Brown-weathering, coarse-grained orthopyroxene-biotite granite (charnockite) has massive and gneissic phases, including schlieren of older gneiss.

At the mouth of the Muskoseu River, 5 km northwest of Wuskwatim Lake, heterogeneous tonalite gneiss occurs in contact with quartz-rich supracrustal units. The tonalitic unit comprises gneissic and foliated phases with orthopyroxene-clinopyroxene-hornblende-biotite-plagioclase-quartz assemblages. Sparse enclaves include garnet-orthopyroxene-biotite paragneiss and orthopyroxene-clinopyroxene-hornblende-plagioclase metabasite. Concordant leucosome and discordant leucogranite dikes are common (Figure GS-8-2a).

At the Muskoseu River locality, a contact interpreted as an unconformity is exposed between a polyphase tonalitic gneiss unit and quartz-rich metasedimentary rocks (Figure GS-8-2a, 2d). The contact is defined by the change from orthopyroxene-bearing tonalitic orthogneiss to quartz-rich rocks with centimetre-scale layering defined by biotite-rich seams. In addition to the evidence for the unconformity provided by this contact, the granulite-facies orthogneiss is inferred to be depositional basement to the quartzite-bearing supracrustal sequence based on several observations: 1) the orthogneiss occurs in structural culminations; 2) the orthogneiss is uniformly at granulite facies, compared to the variable upper amphibolite

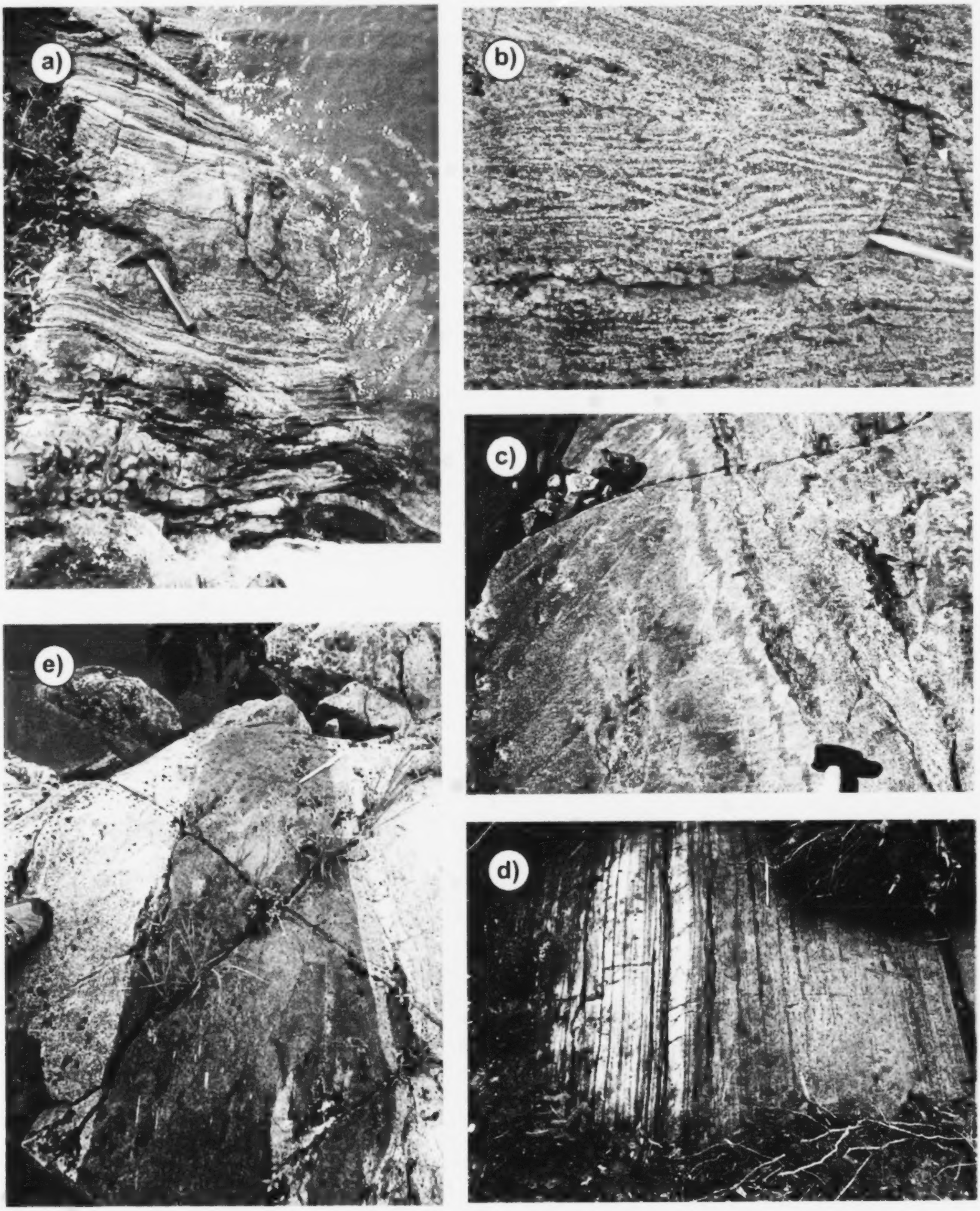

Figure GS-8-2: *Field photographs of characteristic rock types:* ***a)*** *orthopyroxene-biotite tonalite gneiss, Burntwood River near Muskoseu River (33 cm long hammer for scale);* ***b)*** *orthopyroxene-clinopyroxene-biotite tonalite gneiss showing polyphase deformation, Tullibee Lake (9 mm pen barrel for scale);* ***c)*** *metabasite with rusty patches grades into layered sedimentary or volcaniclastic rock, central Wuskwatim Lake (10 cm long hammer head for scale);* ***d)*** *unconformity at the mouth of the Muskoseu River between orthopyroxene-clinopyroxene tonalitic orthogneiss (right) and quartz-rich sandstone (left);* ***e)*** *boudinaged dike with plagioclase phenocrysts cutting orthopyroxene-clinopyroxene tonalite gneiss, Tullibee Lake (11 cm wide boot for scale).*

to granulite facies of the Burntwood Group (Growdon et al., GS-10, this volume); 3) although U-Pb ages are not yet available, the tonalite gneiss at the Muskoseu River location has a model age of 3.3 Ga (Zwanzig et al., GS-9, this volume) and the charnockite from the complex in central Wuskwatim Lake yielded a Nd model age of 3.1 Ga (Percival et al., 2005), both ages similar to those of Superior Province basement to the east; and 4) the orthogneiss is cut by variably boudinaged mafic sills or dikes not present in the nearby Burntwood paragneiss (e.g., Figure GS-8-2e).

Ospwagan-type supracrustal rocks

Occurrences of quartz-rich and associated sedimentary rocks are sporadically exposed in several widely spaced locations. In most locations, they are associated with thin magnetic anomalies where local exposures correspond to sulphide-facies iron formation (Zwanzig et al., GS-9, this volume). In some areas, there appears to be a negative correlation between magnetic anomalies and bedrock exposure. Due to the limited exposure and structural complexity, a composite section has been constructed (Zwanzig et al., Figure GS-9-2, this volume).

Basal quartz-rich units are exposed on the Burntwood River, northwest of Wuskwatim Lake. The arkosic arenite unit is medium- to fine-grained sandstone to siltstone, with layering on the centimetre to metre scale, and an aggregate thickness up to 100 m. Concordant layers and pods of metagabbro constitute up to 5% of the unit. Zircons from quartz-rich sandstone (Nd model ages of 3.1–3.2 Ga) gave U-Pb sensitive high-resolution ion microprobe (SHRIMP) ages between 2.6 and 3.3 Ga (Percival et al., 2005; Zwanzig et al., Figure GS-9-4, this volume). The unit is tentatively correlated with the Manasan Formation of the Ospwagan Group, which also contains exclusively Archean (2.6–2.85 Ga) zircons (Hamilton and Bleeker, 2002; Rayner et al., GS-11, this volume).

Skarn units are exposed in a few locations. At Kawaweyak Lake, a 20 m thick section includes layered and massive carbonate-bearing units with characteristic weathering pits. Calcsilicate assemblages include wollastonite-quartz-carbonate-diopside, with possible vesuvianite. At Wuskwatim Lake, a thinly layered 2 m thick section contains diopside-quartz-calcite. The carbonate-bearing units could correlate with the Thompson Formation of the Ospwagan Group but *see also* Zwanzig et al. (GS-9, this volume).

In a few locations, iron formation is exposed on magnetic anomalies. On the Burntwood River northwest of Wuskwatim Lake, lean sulphide-facies iron formation occurs within garnet- and biotite-bearing semipelite with local calcsilicate-bearing layers. Angular boulders of massive sulphide (pyrrhotite-pyrite) suggest an association with the magnetic anomaly. In northwestern Wuskwatim Lake, a 5 m thick unit of sulphide (pyrrhotite)- and silicate-facies iron formation occurs on a prominent magnetic anomaly. At Kawaweyak Lake, lenses of massive pyrrhotite up to 3 m thick in greywacke and semipelite represent sulphide-facies iron formation. Silicate-facies iron formation pods up to 3 m thick are present in southern and western Threepoint Lake. Elsewhere, garnet- and biotite-bearing semipelite with concordant, millimetre scale quartz veins may represent equivalents of the Pipe Formation. The iron formation–semipelite occurrences are tentatively correlated with the Pipe Formation of the Ospwagan Group.

Burntwood Group metasedimentary rocks

The Burntwood Group consists of metagreywacke and derived schist, migmatite and diatexite. Metamorphic assemblages include combinations of garnet, biotite, cordierite, sillimanite, an inferred melt phase in the amphibolite facies and garnet-orthopyroxene-biotite melt in the granulite facies (*see* Growdon et al., Figure GS-10-1, this volume). Small quantities of graphite are ubiquitous. Migmatitic leucosome constitutes from 5% to 50% of most outcrops and contains garnet in the Wuskwatim Lake area. The migmatite is cut by concordant and discordant leucogranitic pegmatite dikes.

Intrusions

Several intrusive suites are recognized throughout the region. Deformed and metamorphosed metabasite occurs as dikes and boudins within tonalitic gneiss and quartz-rich metasedimentary units (Figure GS-8-2e). At Kawaweyak Lake, an ~15 m thick gabbro-pyroxenite body cutting sulphidic iron formation contains metre-scale zones of massive pyrrhotite, closely resembling the setting of Thompson-type mineralization. At Tullibee Lake, a 10 m thick gabbro sill within Burntwood paragneiss exhibits 1 to 20 cm igneous pyroxenite layers. Sheets of biotite granodiorite and orthopyroxene-biotite granodiorite cutting Burntwood paragneiss in the Tullibee Lake area are strongly foliated and reflect regional deformation patterns. In the Wuskwatim Lake area, small bodies of massive garnet-biotite granite and garnet-orthopyroxene-biotite granite appear to postdate regional deformation. Dikes and sills of leucogranite and pegmatite are present throughout the region and have variable timing relationships with respect to regional deformation events.

Four intrusive samples of inferred Paleoproterozoic age were selected for tracer isotope analysis. The four samples form a roughly east-west transect across approximately 100 km of the Kisseynew Domain, from near Footprint Lake to Highrock Lake (Figure GS-8-1). These Paleoproterozoic granitoids act as probes, their Sm-Nd signatures indicating the presence or absence of ancient crust beneath Burntwood paragneiss. Details

Table GS-8-1: Location and lithology of samples collected for Sm-Nd isotope analysis, from west to east, northeastern Kisseynew Domain.

Lab number	Sample number	Rock type	UTM zone	UTM E	UTM N
8958	25-72-4030	gneissic garnetiferous granodiorite	14	413748	6170734
8957	25-71-328	porphyroblastic granite	14	463212	6179568
8956	25-73-1455	gneissic granite	14	481102	6200749
8955	29-71-412	porphyroclastic granite-monzonite	14	511677	6183356

UTM coordinates measured using NAD 83

of the rock types and specific locations are found in Table GS-8-1 and are listed from west to east.

Tracer isotopic analyses were conducted using the multicollector ICP-MS Nu Plasma™ at the Geological Survey of Canada. Samarium and Neodymium were analyzed using an array of fixed Faraday collectors in static multicollector mode. The isotopic ratios were corrected for spike contribution and mass discrimination by numeric solution of the isotope dilution equations with exponential normalization. Quality control was performed by monitoring the uniformity of nonradiogenic isotopic ratios and by analyzing of the standards (La Jolla Nd and Ames Sm). Analytical results are presented in Table GS-8-2 and plotted on Figure GS-8-1, except for sample 25-72-4030 from Highrock Lake to the west of the figure area. Model ages (Goldstein et al., 1984) range from 1.91 to 2.85 Ga, indicating crustal contamination; however, there does not appear to be a systematic decrease in model ages moving away from the Superior margin as would be expected for a continuous margin that thins to the west.

Structural elements

At least four phases of deformation have affected the Burntwood Group regionally (cf. Zwanzig, 1990; Zwanzig and Böhm, 2002) and three of these (D_{2-4}) are recognized in the Wuskwatim corridor. The principal outcrop-scale fabric is a synmetamorphic S_2 foliation and migmatitic layering, through which older events are inferred based on map relationships.

Pre-D_1 (Archean) fabrics

In exposures of tonalitic gneiss on Wuskwatim Lake, boudinaged metagabbro dikes transect an early gneissic layering. The dikes are observed in basement gneiss and quartz-rich metasedimentary units, but generally not in Burntwood Group paragneiss, analogous to the timing of the 1.883 Ga Molson dike swarm of the Thompson Nickel Belt (Bleeker, 1990). Based on this analogy, the gneissic fabric defined by granulite-facies minerals could represent a pre–1.883 Ga high-grade tectonothermal event, possibly an Archean fabric of Superior Province affinity. Little additional information can be drawn from these observations owing to the strong Proterozoic tectonothermal overprint.

Deformation D_1: early thrusting

An early (D_1) period of Paleoproterozoic deformation was inferred based on map relationships at the Mel zone, 60 km northeast of Wuskwatim Lake (Zwanzig and Böhm, 2002; Zwanzig et al., GS-9, this volume). Similar tectonostratigraphic assemblages are present in this

Table GS-8-2: Analytical results for samples collected for Sm-Nd isotope analysis, northeastern Kisseynew Domain.

Sample number	Sample wt, g	Age, Ga (assumed)	[Nd][1] ppm	[Sm][1] ppm	^{147}Sm[1]/^{144}Nd	2σ[1]	^{143}Nd[2]/^{144}Nd	2σ[2]	ε^{143}Nd[3]	TDM, Ma (Goldstein)
25-72-4030	0.097	1.84	43.37	8.17	0.114	0.000	0.512	0.000	0.20	2297
25-71-328	0.098	1.84	70.08	9.80	0.085	0.000	0.511	0.000	-10.90	2851
25-73-1455	0.098	1.84	159.02	33.90	0.129	0.000	0.512	0.000	5.31	1915
29-71-412	0.102	1.84	70.08	9.78	0.084	0.000	0.511	0.000	-9.88	2790
29-71-412 (dupl.)	0.096	1.84	69.43	9.69	0.084	0.000	0.511	0.000	-9.94	2793

[1] Sm and Nd concentrations and ^{147}Sm/^{144}Nd ratios are corrected for blank of 2 ±2 pg for both Sm and Nd. The uncertainty is propagated into the error of ^{147}Sm/^{144}Nd ratio

[2] Nd isotopic ratios are corrected for fractionation relative to the ratio of ^{146}Nd/^{144}Nd = 0.7219, using exponential law and real atomic masses. The ^{143}Nd/^{144}Nd isotopic ratios are adjusted to ^{143}Nd/^{144}Nd = 0.51186 in the La Jolla standard.

[3] ε^{143}Nd at the time indicated in the column "Age, Ga" relative to the accepted Chondritic Uniform Reservoir with ^{143}Nd/^{144}Nd = 0.512636 and ^{147}Sm/^{144}Nd = 0.1966.

location, including Superior Province basement, Ospwagan Group strata and Burntwood Group paragneiss. A D_1 thrust is inferred to have placed Burntwood Group metagreywacke over the Pipe Formation of the Ospwagan Group, cutting out stratigraphically higher units of the Ospwagan Group. Observed in several drillcores, deformed strata are parallel and the contact is invariably obscured by intrusive material (Zwanzig et al., 2003). In the Wuskwatim Lake corridor, Burntwood paragneiss structurally overlies iron-formation-bearing units tentatively correlated with the Pipe Formation, presenting a similar relationship.

Deformation D_2: synmetamorphic layering

A prominent synmetamorphic D_2 foliation and migmatitic layering is the dominant outcrop-scale fabric element in most units. Defined by alignment of biotite grains, leucosome veins and mesosome selvages, the fabric parallels bedding in sedimentary units, where preserved. In a few locations, a component of shear strain is apparent in the D_2 fabric. The offset of markers indicates ductile, top-to-the-south shear. The D_2 structures are inferred to have formed in subhorizontal orientations throughout most of the area, and were subsequently folded about upright F_3 folds.

Structural analysis of the KD in Manitoba (Zwanzig, 1990) and detailed analysis of its southern flank (Zwanzig, 1999), as well as ongoing work at the margin of the TNB indicate that D_2 spans a protracted period (probably 1.82–1.79 Ga), with several phases of folding and a variety of structural styles. Where these originally west-northwest-trending structures are tracked over an extended area, they include midcrustal recumbent folds and upper crustal inclined to upright structures. The same crustal-scale geometry is inferred in the Wuskwatim Lake corridor (see below) and suggests a protracted development of the structural culminations that expose the older gneisses in the northeastern KD.

Large-scale D_2 structures are probably responsible for the interleaving of the relatively thin structural sheets of the heterogeneous Archean-derived gneiss units with the juvenile Proterozoic Burntwood Group. In the Mel zone, basement gneiss occurs structurally above and below the Burntwood paragneiss, in a probable D_2 nappe-like structure (Zwanzig et al., 2003). Therefore, the possibility of allochthonous basement must be considered in interpreting the structural geometry of the Wuskwatim corridor.

F_3 folds

A set of northeast-trending folds defines the map pattern throughout much of the Wuskwatim corridor. Map units and S_2 foliation in migmatitic rocks are folded into open to tight, upright to northwest-dipping F_3 folds. Moderate northeasterly plunges characterize folds in the northern part of the area. In addition to the map-scale structures, mesoscopic F_3 folds and associated L_3 rodding lineations are common. In some locations, axial surfaces of symmetrical F_3 folds are defined by leucosome segregations. At least one suite of granitic dikes appears to be syntectonic with respect to D_3. At Kawaweyak Lake, a west-trending dike transects a mesoscopic F_3 fold at a high angle, and the dike margin is affected by a fracture cleavage parallel to the F_3 axial surface.

Folds belonging to F_3 are present in submigmatitic Burntwood metagreywacke in a structural basin southeast of Footprint Lake. The northeast-trending folds have subvertical hinges and reorient steeply dipping S_2 cleavage. It is apparent that the dip of S_2 foliation varied significantly prior to D_3 deformation, from gentle in migmatitic rocks, to upright at lower metamorphic grade and presumed higher structural levels.

To the southeast in the Tullibee Lake region, F_3 folds are notably tighter and more upright.

F_4 folds

The interaction between F_3 folds and F_4 crossfolds is inferred to be responsible for dome-and-basin interference patterns and for significant regional structural relief. On the northern flank of a west-northwest-trending F_4 antiform centred on Wuskwatim Lake, map-scale F_3 folds have consistent northeasterly plunges and metamorphic grade decreases from granulite facies through upper amphibolite to mid-amphibolite facies. This structural culmination exposes the basement and Ospwagan-type supracrustal occurrences in the Wuskwatim Lake–Burntwood River–Threepoint Lake region. To the north, an F_4 synform encloses basins of submigmatite-grade Burntwood Group.

Late-metamorphic high-strain zones were observed on the Burntwood River northwest of Wuskwatim Lake (Figure GS-8-3). The west-southwest-trending, steeply dipping protomylonitic to mylonitic fabric involves migmatitic leucosome and pegmatite that elsewhere truncate S_2 foliation. Fractures in orthopyroxene and garnet crystals are filled with quartz. Locally developed shear bands indicate dextral transcurrent displacement. In a few locations, ultramylonite seams up to a few millimetres thick extend over strike lengths of more than 20 cm. A single generation of late granite dikes postdates the straight gneissosity. Based on their orientation and ductile nature, the shear zones are inferred to have formed during D_4 deformation; however, their geometric significance is not understood.

Structural geometry

This section uses field, isotopic (Percival et al., 2005; Zwanzig et al., GS-9, this volume; Rayner et al., GS-11, this volume; Growdon et al., GS-10, this volume) and geophysical information (Coyle and Kiss, 2006) to describe the regional structural geometry.

The regional structures resulting from the polyphase deformation are narrow discontinuous belts of Archean-derived paragneiss marked by high-intensity aeromagnetic signature, hosted in a terrane of the Paleoproterozoic Burntwood Group marked by low magnetic intensity. The structures have an overall northwesterly trend established during the early periods of deformation (D_{1-2}) but generally thrown into open to tight northeast-trending folds during the later phases.

Wuskwatim Lake crossfold

A moderate positive aeromagnetic anomaly beneath Wuskwatim Lake corresponds to exposures of granulite-facies tonalite gneiss and granite (charnockite), interpreted as Archean basement (T_{DM}=3.1 Ga). Subhorizontal S_2 foliation and L_3 lineation characterize the core of the structure. The central anomaly is separated from the surrounding magnetically quiet background, which corresponds to Burntwood paragneiss, by a positive anomaly identified as sulphide-facies iron formation (T_{DM}=3.3 Ga) at one location in the northwest. A gently southwest-plunging F_3 antiform is defined by the orientation of S_2 foliation and layering in the southern part of the structure. Along the axis of the D_3 structure to the northeast is a moderately northeast-plunging F_3 synform. Its juxtaposition with the antiform suggests post-F_3 lateral displacement. The west-southwest-trending, late-metamorphic, high-strain zones could have accommodated this movement. A broad, west-northwest-trending F_4 antiform is inferred to be responsible for the reversal in F_3 plunge. Alternatively, there may have been an independent development of F_3 folds with symmetry reversal and detachment across a northwest-trending F_2 antiform. Such structures have been mapped on the southern flank of the KD (Zwanzig, 1999) and were also achieved in experiments of superposed buckle folding (Skjernaa, 1975). In this interpretation, the late-metamorphic shear zone was long lived and served as a displacement transfer zone during D_3 and as a transpression zone during D_4.

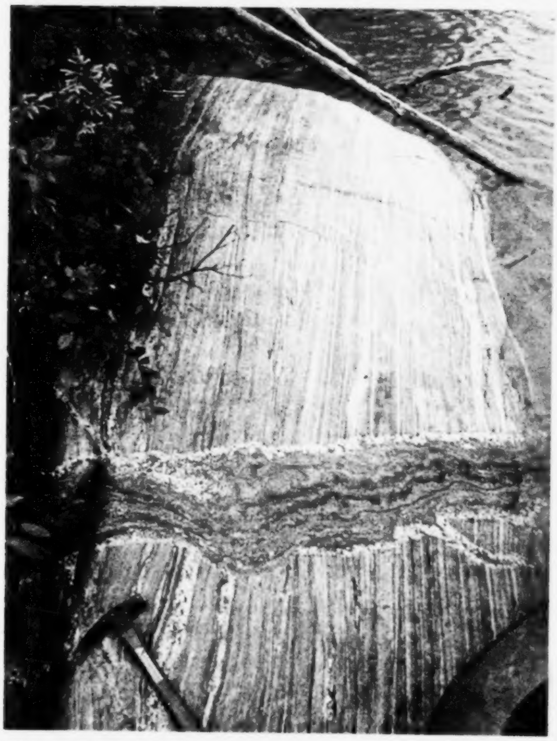

Figure GS-8-3: High-strain zone in quartz-rich sandstone, Burntwood River. Note transposition of pegmatite dikes (pale). The high-strain fabric is transected by a late granite dike.

Burntwood River 'M' fold zone

Neither basement nor quartz-rich supracrustal units can be traced the few kilometres across the synform between Wuskwatim Lake and the Burntwood River, although the lithological components are similar on the river. Gneissic tonalite is exposed in the cores of a pair of narrow, steeply northwest-dipping structural belts of orthogneiss flanked by paragneiss units that are marked by magnetic anomalies. The belts are interpreted as Archean basement with Ospwagan-type cover. The basement in the southern belt is gneissic, granulite-facies tonalite, whereas the basement in the north is orthopyroxene granite (charnockite). The Ospwagan-type section comprises basal quartz-rich sandstone and a greywacke-pelite unit, including sulphide-facies iron formation, which forms the magnetic marker.

The fold zone may represent antiform-synform pairs forming an upright M-shaped structure (Figure GS-8-4). The structure is about 10 km long and 3.5 km wide, including an unexposed area with linear aeromagnetic anomalies northwest of the river. The entire fold zone is surrounded by Burntwood Group migmatite. It is canoe-shaped and tentatively interpreted as an F_3 structure refolded by a northwest-trending F_4 antiform. The structure can alternatively be interpreted as a series of early recumbent folds of Archean orthogneiss with paragneiss cover, structurally overlain by the Burntwood Group along a roof thrust (Figure GS-8-4c). In this interpretation, a tight F_3 antiform has refolded the structure along with the thrust and brought it up to the level of erosion. Very similar structures with the same Mesoarchean Nd model ages (Zwanzig et al., GS-9, this volume) occur northeast of Thompson along the northern termination of the TNB. The magnetic anomalies that mark the fold zone on the Burntwood River are truncated abruptly at the southwestern end of the structure, probably along a D_4 shear zone.

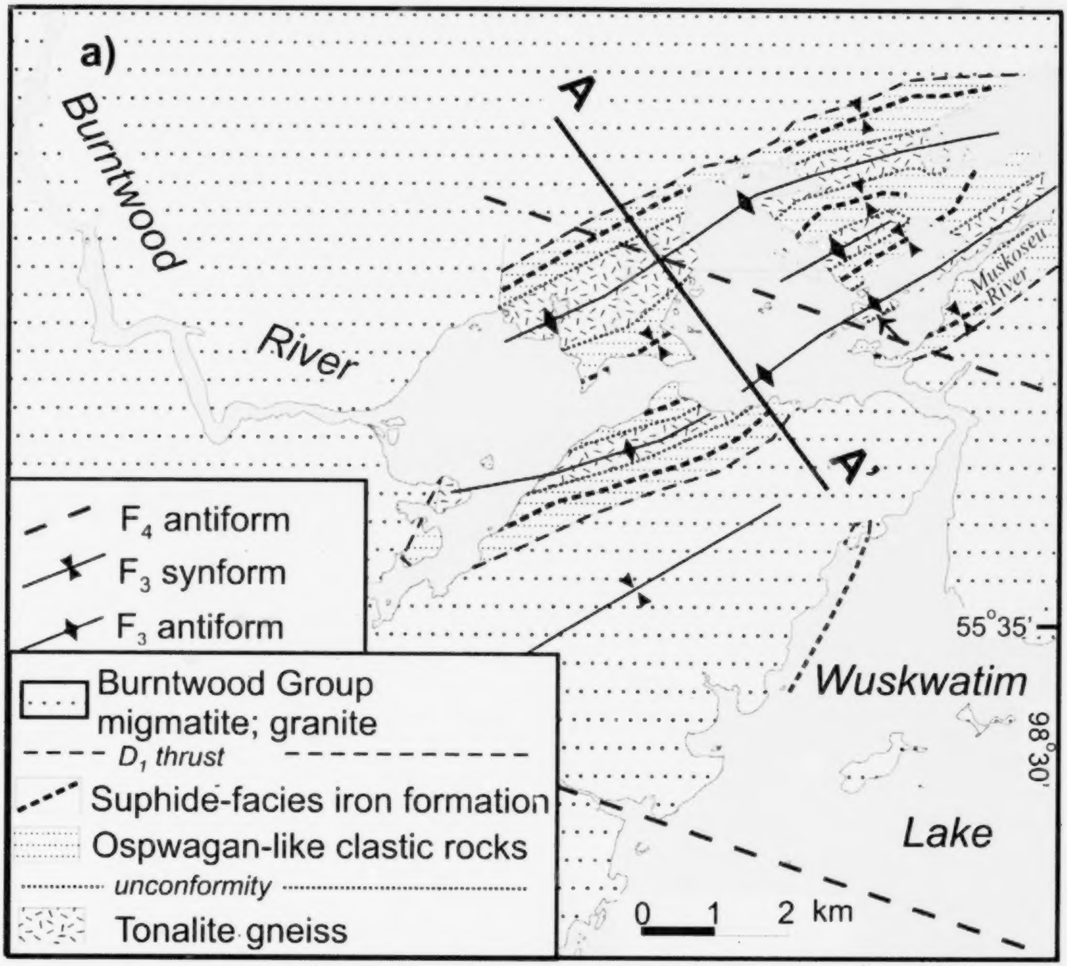
a)
A
A'
Burntwood
River
Muskoseu
River
55°35'
98°30'
Wuskwatim
Lake
0 1 2 km
F4 antiform
F3 synform
F3 antiform
Burntwood Group
migmatite; granite
D1 thrust
Suphide-facies iron formation
Ospwagan-like clastic rocks
unconformity
Tonalite gneiss
b)
A
A'
0 1 2 km
c)
A
A'
F1 antiform
0 1km
?

***Figure GS-8-4:** Burntwood River area northwest of Wuskwatim Lake; **a)** map showing field relationships, with the location of the exposed unconformity at the mouth of the Muskoseu River indicated by the small arrow; **b)** interpretive cross-section; **c)** alternate interpretive cross-section.*

Threepoint Lake

The structure at Threepoint Lake is dominated by a large F_3 antiform-synform pair in the central and eastern bays, and west-northwest linear trends to the west. The antiform is cored in a large folded granite pluton with a hypersthene-bearing phase that intruded mainly the Burntwood Group. Felsic gneiss derived from arkosic quartzite, amphibolite, garnet-biotite gneiss and sulphidic gneiss, all interpreted to be part of the Ospwagan-like sequence, occur on small isolated shoreline outcrops on an elongate island on the northwestern limb of the antiform. Abundant granite shows that these rocks may represent large rafts at the margin of the pluton. A magnetic anomaly in the strait to the northwest suggests the presence of iron formation. Similar rocks, but containing mostly garnet-biotite, and sillimanite-biotite gneiss, commonly with disseminated pyrrhotite, as well as hypersthene intermediate gneiss, extend west along the north shore of the western bay. As on the Burntwood River northwest of Wuskwatim Lake, the narrow belt of heterogeneous paragneiss is bounded on the north and south by the Burntwood Group and is therefore interpreted as a thrust sheet, possibly refolded into a tight early recumbent fold.

Narrow magnetic anomalies extend also for 15 km northeast along the flooded Burntwood River on the southeastern limb of the F_3 synform. There is little present exposure, but previous mapping (Baldwin et al., 1979) has suggested that the anomalies also mark a thin sheet of heterogeneous gneiss and amphibolite. The east-trending river channel to the south has small outcrops of sheared orthogneiss and highly foliated granitoid rocks, including multiphase agmatite, that appear to occupy another long-lived east-trending shear zone. The gently to moderately northeast-plunging core of the synform is occupied by garnet-biotite schist and metagreywacke with only traces of quartz-plagioclase veining. The nearest occurrence of hypersthene is in intrusive rock of intermediate composition (possible enderbite), only 5 km south of the nonmigmatitic rocks. The average dip of 40°N indicates that biotite-granulite–facies rocks presently occur only 3 km below the roof of the migmatite complex. This suggests considerable post-peak thermal attenuation of the structures in the northeastern KD or anomalously high paleothermal gradients.

Tullibee and Neuls lakes

High-grade tonalite gneisses containing boudinaged mafic dikes represents probable Archean basement in western and central Tullibee Lake. Prominent north-northwest-trending magnetic anomalies arise from strongly foliated, biotite-magnetite granodiorite of probable Paleoproterozoic age. Less than 2 km to the west at Neuls Lake, sulphide-facies iron formation and metagabbro occur within quartz-rich sandstone and semipelite, inflated more than 50% by dikes of granite and pegmatite. The iron formation forms a linear magnetic high that is part of a chain of positive anomalies that describe north-trending folds in the poorly exposed area south and west of Neuls Lake. An Ospwagan-like package, dismembered by Paleoproterozoic intrusions, may be present in this region.

Possible regional extent

Based on the distribution of observed Ospwagan-like supracrustal rocks and gneisses of probable Archean age with Superior Province affinity, it is suggested that the Superior margin basement and its cover sequence, exposed in structural culminations and thin sheet-like structures through Burntwood migmatite, extends at least 60 km west of the Thompson Nickel Belt into the Kisseynew Domain. Because the basement-cover sequence occurs in structural culminations, it is likely that Archean basement underlies this part of the Kisseynew Domain. It is also possible that the sequence represents the upper limb of a large F_2 nappe structure such as that suggested to occur in the Mel zone (cf. Zwanzig et al., 2003). Evidence for the latter is provided by the long sheet-like structures bounded by thicker packages of Burntwood Group migmatite and by the presence of long-lived shear zones locally containing a variety of foliated intrusive rocks. The larger domes of granulite-facies orthogneiss, best interpreted as basement, and the overall high gravity signature of the northeastern part of the KD (e.g., White et al., 2005), however, suggest that Archean granulite with remnants of cover rocks may constitute much of the crust below the present level of exposure. In addition to the structural observations, ca. 1840 Ma granitoid rocks within this 60 km wide zone show Nd isotopic evidence of contamination by Archean crust (this study), which is inconsistent with a model involving post-Burntwood collisional emplacement of a thin nappe of basement. At the present level of knowledge, it is also possible that the ancient crust occurs as rifted epicratonic fragments (Percival et al., 2005).

Using the structural geometry model developed in the Wuskwatim corridor, the authors infer that a second belt of Ospwagan-like rocks may be present north of Highway 391 (Figure GS-8-1). Occurrences of supracrustal rocks at Osik and Mooswuchi lakes (Baldwin et al., 1979), in addition to those described at Kawaweyak Lake, may represent an Ospwagan-like sequence. It is unlikely that the package extends as far west as Notigi Lake, based on the juvenile Nd signature of Paleoproterozoic granitoid rocks in that area (Figure GS-8-1).

Economic Considerations

A major implication of this work is that Thompson-type nickel mineralization may exist within the Ospwagan-like strata present in the 60 km wide zone west of the Thompson Nickel Belt proper. Although a complete stratigraphic section is not preserved, the most economically prospective part of the section — sulphide iron-formation-bearing rocks equivalent to the Pipe Formation — are present on a regional scale. Furthermore, the sulphide-bearing mafic-ultramafic intrusive rocks in the Ospwagan-like section at Kawaweyak Lake provide rare exposures of Thompson-type magmatic rocks. More groundwork and detailed geophysical information are required to map the distribution of Ospwagan-type rocks in that area.

The depth to the basement beneath Burntwood cover is critical in evaluating the economic prospectivity of the eastern Kisseynew Domain. More detailed structural reconstructions, in conjunction with the re-interpretation of seismic reflection profiles (cf. White et al., 2002), are necessary to determine the subsurface configuration of the Ospwagan-like strata.

The region could also have potential for iron-formation-hosted gold mineralization, based on similar environments elsewhere. The presence of stratiform sulphides in iron formation and structurally complex geometry could be significant factors in localizing gold.

A further ramification of the regional observations concerns diamond prospectivity. The inference that Archean basement underlies the eastern 60 km of the Kisseynew Domain presents the possibility that Archean mantle lithosphere is attached, with its enhanced diamond potential. Kimberlitic intrusions within this zone would therefore be more prospective than areas further west.

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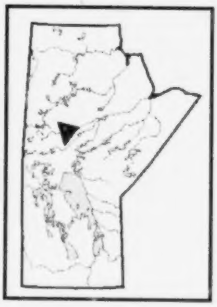
GS-9

Thompson Nickel Belt–type units in the northeastern Kisseynew Domain, Manitoba (parts of NTS 63O)

by H.V. Zwanzig, L. Murphy, J.A. Percival[1], J.B. Whalen[1]
and N. Rayner[1]

Zwanzig, H.V., Murphy, L., Percival, J.A., Whalen, J.B. and Rayner, N. 2006: Thompson Nickel Belt–type units in the northeastern Kisseynew Domain, Manitoba (parts of NTS 63O); *in* Report of Activities 2006, Manitoba Science, Technology, Energy and Mines, Manitoba Geological Survey, p. 85–103.



Summary

Remapping a corridor from the Thompson Nickel Belt (TNB) 60 km west to Threepoint Lake (south of Nelson House) and a preliminary interpretation of geochemistry and Nd isotope data provide new evidence for an Archean age of crystallization and/or mantle extraction of biotite granulite facies orthogneiss in the northeastern part of the Kisseynew Domain. The gneiss occurs in local structural culminations mantled by, and probably interleaved with, heterogeneous paragneiss that may overlie it unconformably. A composite stratigraphic section through the narrow belts of this paragneiss comprises basal quartzite (containing only Archean detrital zircons) and minor calcsilicate gneiss, overlain by garnet-biotite gneiss and aeromagnetically prominent sulphide-facies iron formation. The succession has distinct similarities to the lower half of the cover rocks (Ospwagan Group) on the Archean basement in the TNB, but also some problematic differences. These narrow units are in fault contact with widespread juvenile Paleoproterozoic migmatite (Burntwood Group) derived from volcanic-arc sedimentary rocks. A preliminary interpretation suggests that a large region, which seems to be structurally underlain by these rocks, may be a major exploration frontier for Thompson-type nickel deposits. This assumes that the correlation of these rocks with the Ospwagan Group is confirmed by more rigorous examination, including planned analytical work and further mapping.

Introduction

A new aeromagnetic survey (Coyle and Kiss, 2006) and a geological mapping project (Percival et al., GS-8, this volume) were started west of the Thompson Nickel Belt (TNB) as a result of several recent observations. The recent findings include granite that is highly contaminated with Archean crust (Zwanzig et al., 2003), granulite-facies orthogneiss believed to be Archean basement, and supracrustal rocks with exclusively Archean detrital zircons (Percival et al., 2004, 2005). The project extends over a triangular area from Tullibee Lake in the south, along Highway 391 in the north and west to Threepoint Lake, more than 60 km west of the TNB. It covers much of the northeastern part of the Kisseynew Domain (KD) in the internal zone of Trans-Hudson Orogen (Figure GS-9-1). The general region is marked by a high-gravity anomaly (Viljoen et al., 1999)

The area, which was last mapped between 1971 and 1973 (Baldwin et al., 1979; Frohlinger and Kendrick, 1979; Kendrick, 1979a–c; Kendrick et al., 1979), has been considered until recently to be underlain solely by juvenile Paleoproterozoic greywacke-mudstone migmatite (Burntwood Group), local meta-arkose (Sickle Group) and granitoid rocks largely derived by partial melting of the metasedimentary rocks (e.g., White, 2005). A heterogeneous unit (mapped as unit 5 by Baldwin et al., 1979), containing amphibolite and paragneiss that includes sulphide-facies iron formation, grades into arkosic quartzite that was assigned to the Sickle Group. The quartzite, however, contains only Archean detrital zircons (Percival et al., 2004, 2005) that are uncommon in the Sickle Group (and its deep-marine facies, the Burntwood Group) because these groups have a provenance in the Paleoproterozoic arc terrane to the north. The quartzite and associated paragneiss appear to form an unrelated heterogeneous succession that can be compared to units in the TNB, which they resemble. The amphibolite appears to be largely intrusive. The small available exposures of these rocks were examined in detail and sampled to provide petrographic, geochemical, isotopic and structural data for the comparison.

The project area has less than 1% outcrop in the south and east, commonly separated by muskeg and low bush. Thus, the new mapping relies heavily on the recent aeromagnetic survey and on the few scattered clean outcrops along shorelines. Early results show that the Burntwood Group was mapped reliably, although the granitoid rocks are not sufficiently peraluminous to be S-type as suggested (but can be assigned a proper origin from archived samples). Moreover, ‘unit 5’ and the quartzite need to be remapped and resampled. To that end, an area measuring 6 km by 8 km was explored at Tullibee Lake (parts of NTS 63O2 and 7) and a 12 km wide corridor was remapped across the Wuskwatim–Threepoint lakes area (parts of NTS 63O10 and 11). Reconnaissance mapping was done along Highway 391, at Kawaweyak Lake (parts of NTS 63O7 and 8) and

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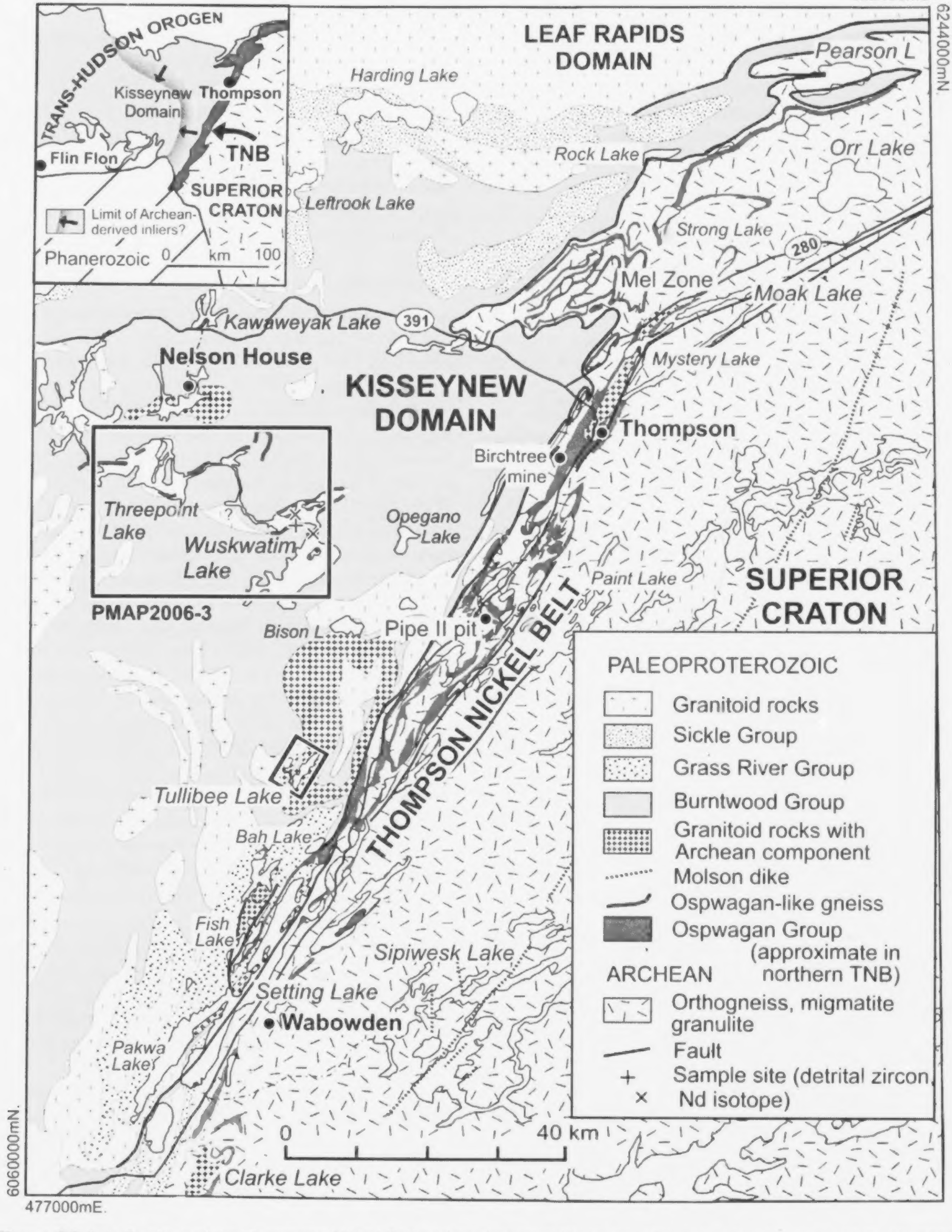
622400mE.
6244000mN.
LEAF RAPIDS DOMAIN
Pearson L
Harding Lake
Rock Lake
Orr Lake
Leftrook Lake
Strong Lake
280
Mel Zone
Moak Lake
Kawaweyak Lake
391
Mystery Lake
Nelson House
KISSEYNEW DOMAIN
Thompson
Birchtree mine
Threepoint Lake
Wuskwatim Lake
PMAP2006-3
Opegano Lake
Paint Lake
SUPERIOR CRATON
Bison L.
Pipe II pit
THOMPSON NICKEL BELT
Tullibee Lake
Bah Lake
Fish Lake
Sipiwesk Lake
Setting Lake
Wabowden
Pakwa Lake
Clarke Lake
0
40 km
6060000mN.
477000mE.
TRANS-HUDSON OROGEN
Kisseynew Domain
Thompson
Flin Flon
TNB
SUPERIOR CRATON
Limit of Archean-derived inliers?
Phanerozoic
0
km
100
PALEOPROTEROZOIC
Granitoid rocks
Sickle Group
Grass River Group
Burntwood Group
Granitoid rocks with Archean component
Molson dike
Ospwagan-like gneiss
Ospwagan Group (approximate in northern TNB)
ARCHEAN
Orthogneiss, migmatite granulite
Fault
+ Sample site (detrital zircon,
× Nd isotope)

Figure GS-9-1: *Geology of the Thompson Nickel Belt and northeastern Kisseynew Domain, showing areas visited in 2006 with narrow belts of Ospwagan-like gneiss and sample sites for sensitive high-resolution ion microprobe (SHRIMP) detrital zircon ages and Nd isotope and geochemical data; large box shows area covered by Preliminary Map PMAP2006-3 (Zwanzig et al., 2006); inset map shows the limit of an area in the northeastern Kisseynew Domain that may contain northern Superior–type Archean crust, indicated also by highly contaminated granite.*

Notigi Lake (63O16). A day of helicopter work covered an area east and north of Tullibee Lake and at Opegano Lake.

The purpose of this new project is to compare the heterogeneous gneiss units and other rocks marked by magnetic anomalies (previously unit 5 and Sickle Group) along the Wuskwatim Lake corridor to similar rocks with proven mineral potential in the TNB. This work is designed to support and promote nickel exploration and possible gold exploration in the Thompson–Nelson House–Wabowden region. The general geology, structure and a preliminary field interpretation of the area are in a companion report (Percival et al., GS-8, this volume). Preliminary findings regarding metamorphic mineral assemblages, textures and relationships to structure and tectonostratigraphy are given in Growdon et al. (GS-10, this volume).

This report attempts to organize the various gneissic units that do not belong to the Burntwood Group greywacke-derived migmatite into a coherent tectonostratigraphy. The focus is on paragneiss units that resemble the Ospwagan Group, which hosts the nickel deposits in the TNB. Preliminary results are derived from petrography, geochemistry, Nd isotope geology and a review of detrital zircon geochronology. Time and budget constraints have limited this work to modal analysis and geochemistry of 11 samples, Nd isotope work on 7 new samples, and zircon geochronology replotted from one sample. Nevertheless, these limited data are tied into a rich database gathered over the past 8 years in the TNB, in the recently explored northern TNB extension and from some anomalous rocks on the margins of the TNB.

Preliminary tectonostratigraphy

Poor outcrop make an aeromagnetic interpretation critical in the northeastern KD. Therefore the regional distribution of units, which is the basis for a tectonostratigraphic interpretation, relies on the magnetic pattern and on ground truthing that was carried out during the 2006 field work. The magnetic units occur within narrow belts of paragneiss, less than 750 m wide and commonly exposed along shorelines parallel to strike, where full cross-sections are not available. Therefore, the unit-scale layering had to be inferred from numerous short shoreline sections, with structural interpretations being used to link them in a composite section.

A relatively good composite section (Figure GS-9-2) was assembled where the Burntwood River is widened by flooding near its exit into Wuskwatim Lake (Zwanzig et al., 2006). A short section that is oblique to the northwest shore of Wuskwatim Lake provided additional samples along 200 m of discontinuous shoreline exposure. Another composite section was assembled on Threepoint Lake.

Local sections of nickel belt-like paragneiss

The best composite sedimentary section is intermittently exposed on small islands and along the south shore of the flood-widened Burntwood River northwest of Wuskwatim Lake (Percival et al., GS-8, this volume, Figure GS-8-4a). Orthopyroxene-biotite-grade paragneiss mantles the southeastern contact of a belt of granulitic multicomponent orthogneiss that is 250 to 600 m wide. The steeply dipping southeastern contact is tentatively interpreted as an unconformity, and the paragneiss is interpreted to face southeast and to be structurally overlain by the Burntwood Group. The succession is 500 to 600 m wide, with arkosic quartzite adjoining the orthogneiss and a prominent linear magnetic anomaly marking the upper part of the section. The top is confined to low ground and features only locally exposed sulphidic schist and gneiss.

This sequence is followed by bedded quartz-rich gneiss with calcsilicate minerals in a section that may be 150 m thick. About 70 m to the southeast is garnet-biotite schist that is interpreted to be Burntwood Group greywacke gneiss. Near the sulphidic paragneiss where the river enters the lake, a protomylonite is interpreted to have been Burntwood Group rocks that were deformed in a major early fault zone that was subsequently reactivated in a late-kinematic shear zone.

A similar paragneiss section is exposed on the north side of the belt of orthogneiss on the south shore of the flooded area, 4 to 5.5 km west of the river exit. The shoreline exposes mainly arkosic quartzite, interpreted as the base of a north-facing succession. The quartzite is a maximum of 100 m thick, but much thinner at the west end of the belt where mylonitic quartzite is interlayered with sheared garnet-biotite gneiss. Minor chert and lean sulphide-facies iron formation are exposed within 100 m of the orthogneiss. The entire belt of paragneiss is only 400 m wide at this location despite presumed large-scale folding (Percival et al., GS-8, this volume Figure GS-8-4a). At the east end of the belt, sulphide-facies iron formation occurs with garnet-biotite gneiss 250 m above (north of) the quartzite. This locality marks the west end of a strong linear magnetic anomaly that extends more than 10 km northeast and is interpreted to be caused by thicker unexposed iron formation (Zwanzig et al., 2006). The iron formation–bearing section appears to be underlain at the shore to the south by a thin unit of diopside calcsilicate gneiss.

Outcrops on a small island at the west end of the widened river area indicate that a second belt of orthogneiss lies northwest of the paragneiss section. Orthogneiss exposed on the south and west shores of the island and quartzite exposed on the northeast corner suggest that another narrow belt of heterogeneous paragneiss occurs to the northwest (above the assumed unconformity). A strong linear magnetic anomaly, about 7.5 km long, indicates the

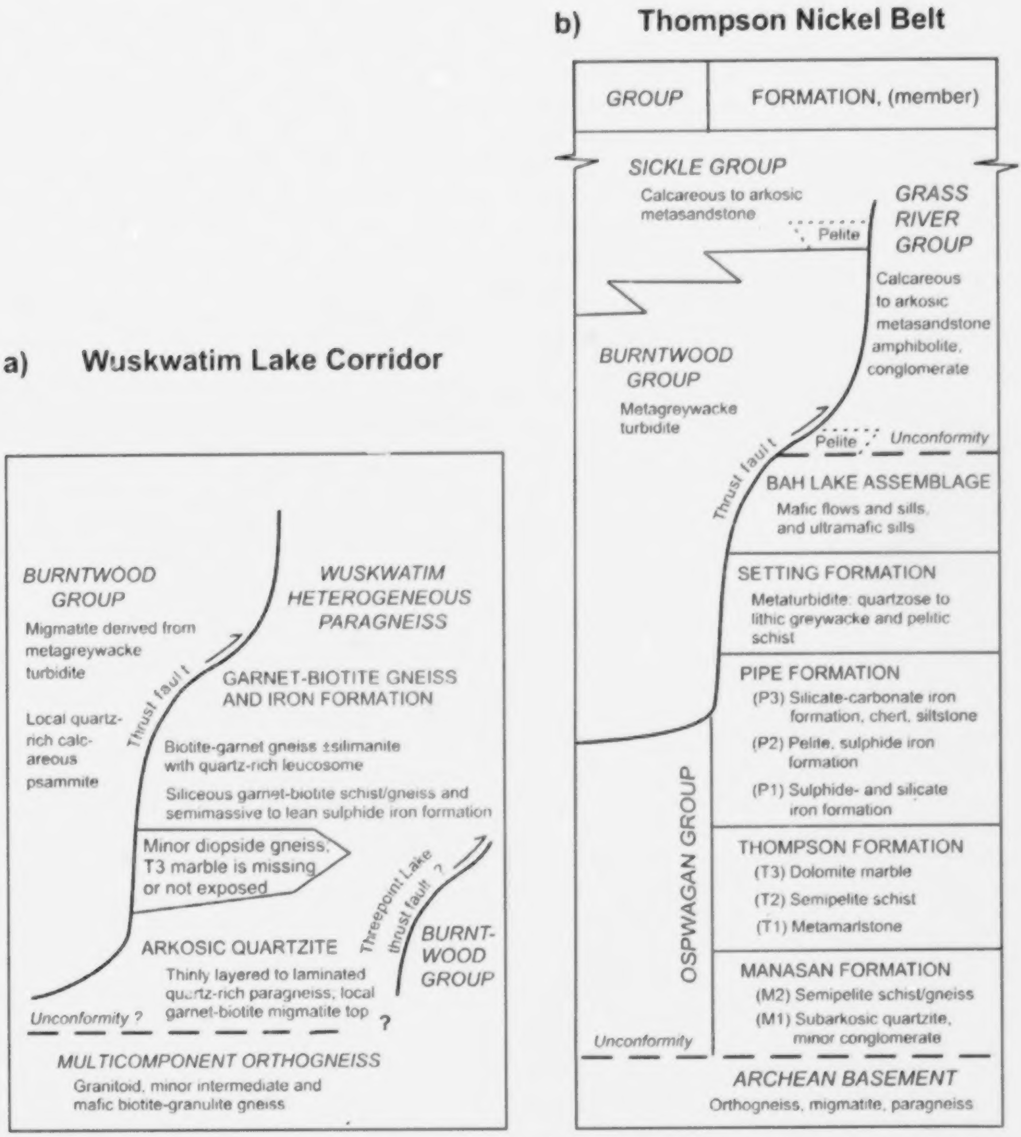
a) Wuskwatim Lake Corridor
BURNTWOOD GROUP
Migmatite derived from metagreywacke turbidite
Local quartz-rich calcareous psammite
Thrust fault
WUSKWATIM HETEROGENEOUS PARAGNEISS
GARNET-BIOTITE GNEISS AND IRON FORMATION
Biotite-garnet gneiss ±silimanite with quartz-rich leucosome
Siliceous garnet-biotite schist/gneiss and semimassive to lean sulphide iron formation
Minor diopside gneiss; T3 marble is missing or not exposed
Threepoint Lake thrust fault
?
BURNTWOOD GROUP
ARKOSIC QUARTZITE
Thinly layered to laminated quartz-rich paragneiss, local garnet-biotite migmatite top
Unconformity ?
?
MULTICOMPONENT ORTHOGNEISS
Granitoid, minor intermediate and mafic biotite-granulite gneiss
b) Thompson Nickel Belt
GROUP
FORMATION, (member)
SICKLE GROUP
Calcareous to arkosic metasandstone
Pelite
GRASS RIVER GROUP
Calcareous to arkosic metasandstone amphibolite, conglomerate
BURNTWOOD GROUP
Metagreywacke turbidite
Thrust fault
Pelite
Unconformity
BAH LAKE ASSEMBLAGE
Mafic flows and sills, and ultramafic sills
SETTING FORMATION
Metaturbidite: quartzose to lithic greywacke and pelitic schist
PIPE FORMATION
(P3) Silicate-carbonate iron formation, chert, siltstone
(P2) Pelite, sulphide iron formation
(P1) Sulphide- and silicate iron formation
OSPWAGAN GROUP
THOMPSON FORMATION
(T3) Dolomite marble
(T2) Semipelite schist
(T1) Metamarlstone
MANASAN FORMATION
(M2) Semipelite schist/gneiss
(M1) Subarkosic quartzite, minor conglomerate
Unconformity
ARCHEAN BASEMENT
Orthogneiss, migmatite, paragneiss

***Figure GS-9-2:** Simplified composite tectonostratigraphic section in the Wuskwatim Lake corridor, northeastern Kisseynew Domain, compared to the type section of the Ospwagan Group in the Thompson Nickel Belt.*

presence of iron formation. A third linear anomaly over areas of flooding and drift 1 to 2 km to the northwest may represent a similar unexposed section of paragneiss.

The paragneiss and iron formation also occur on the northwest shore of Wuskwatim Lake. Bedding strikes locally at high angles to the northeast-trending shoreline, but strike is variable, suggesting that the section is near the hinge of a large fold. Highly pelitic gneiss north of sulphide-facies iron formation is followed by weakly calcareous psammitic gneiss and typical Burntwood Group migmatite. This section is therefore interpreted to be the same as the upper part of the main southeast-facing sequence near the Burntwood River exit, but lying in the northwest-facing limb of a synform that separates these localities. The magnetic anomaly of this succession extends for 10 km in Wuskwatim Lake along the northwest shore. It is separated from the nearest exposure of multicomponent orthogneiss by a calculated true thickness of 850 m of unexposed rock with the magnetic signature of the orthogneiss, which suggests only a thin sequence of paragneiss along the shore.

A section of paragneiss that also resembles the Ospwagan Group in the TNB was traced intermittently for 7.5 km in small exposures along the northwest shore of Threepoint Lake at the mouth of the Rat River and on an island in the lake. This succession, which is underlain and overlain by the Burntwood Group in the west, is overturned and faces the pluton that intrudes it in the main part of the lake (Zwanzig et al., 2006).

Multicomponent orthogneiss

The orthogneiss has a tonalitic to granodioritic and less commonly granitic composition, with minor layers and enclaves of mafic granulite and amphibolite boudins recognizable as mafic dikes. Orthopyroxene-bearing felsic phases weather light brown and range from uniform to gneissic, some with thin concentrations of biotite in the foliation. The moderately to strongly developed foliation is evidence of high strain. The gneiss contains local isoclinal, intrafolial folds and is generally intruded by sheets of pegmatite that locally cut its gneissic layering (Figure GS-9-3a). These features are all similar to TNB basement gneiss. Therefore, the contact with the sedimentary rocks is interpreted as an unconformity. If so, protracted deformation and metamorphism have likely transposed any angular discordance that was present at this unconformity.

Units of orthogneiss consist of assemblages including quartz, plagioclase, finely perthitic microcline, biotite, magnetite, ±clinopyroxene ±orthopyroxene ±garnet ±titanite ±monazite ±zircon and, in mafic to intermediate compositions, ±amphibole. Orthopyroxene crystals are generally only 1 to 2 mm long. They are interpreted as Paleoproterozoic in age, unlike the prominent clusters of grains that are commonly more than 10 mm long in the Archean granulite basement on the southeast side of the TNB. Moreover, unlike the Archean orthopyroxene, they are not generally retrogressed to amphibole as in the basement of the central TNB. Instead, they have thin rims and cracks filled with bastite that make them appear rusty brown on many outcrops.

Arkosic quartzite

Quartzitic paragneiss weathers from almost white to pale brown or buff. It is interpreted to lie unconformably on the multicomponent orthogneiss (Percival et al., GS-8, this volume, Figure GS-8-2d). Where this is interlayered with quartzite, there is strong deformation to obscure the relationship. The unit thickness ranges from less than 1 m to somewhat less than 100 m. The top appears to be interlayered with garnet-biotite migmatite at the base of the pelitic unit. The quartzite is locally cut by concordant or boudinaged mafic to intermediate dikes and widely cut by pegmatite or granite. Arkosic quartzite is massive, or more generally layered at the centimetre scale and laminated at the millimetre scale. This structure is interpreted as highly flattened, transposed bedding (Figure GS-9-3b). Biotite-rich partings are common, and thin interbeds of pelite converted to schist occur especially in the upper part of the unit. These features resemble the Manasan quartzite in the TNB, but the upward gradation into semipelite with abundant sillimanite (M2 member) is not apparent.

Field estimates of quartz content are 60–80%, with the remainder being feldspar, biotite (<10%) ±magnetite ±garnet ±sillimanite/hornblende ±calcite ±various accessory minerals (locally including zircon).

Preliminary detrital zircon results reported in Percival et al. (2005) suggest that the arkosic quartzite from this section contains only or mainly Archean detritus. These results are reviewed later in this paper.

Garnet-biotite gneiss and migmatite

The rocks lying directly on quartzite form only a few small outcrops. They include garnet-biotite migmatite that locally resembles greywacke-derived Burntwood Group paragneiss. A felsic variety is estimated to have about equal parts of quartz and plagioclase, 10 to 15% K-feldspar and up to 15% biotite plus chlorite, with local altered orthopyroxene and minor calcite and epidote. This may be a much-abbreviated upper part of the Manasan Formation (M2), but this is a very unreliable correlation. The unit is generally highly sheared.

Diopside gneiss

A 50 cm thick unit of diopside calcsilicate gneiss, which is interpreted to be sedimentary in origin, occurs within biotite±garnet±orthopyroxene gneiss. The layer is exposed on the north shore of the widened Burntwood River and may be part of a thicker unit underlying the river. It is pale grey-green and comprises mainly clinopyroxene and lesser plagioclase and minor calcite. This unit is of particular interest because similar layers occur in the Thompson Formation, a prominent stratigraphic marker in the Ospwagan Group in the TNB.

Quartzose garnet-biotite gneiss and iron formation

This marker unit forms the upper exposed part of the paragneiss succession in several of the sections. It comprises rusty- to grey–weathering, siliceous and pelitic, garnet-biotite schist and gneiss that contain one to several interbeds of sulphide-facies iron formation. In its rare exposures, the iron formation forms prominent rusty-weathering subunits 1 to 3 m thick (Figure GS-9-3c). They are highly magnetic, with about 30% pyrrhotite±magnetite. An angular boulder of graphitic massive sulphide at one of the magnetic anomalies (Percival et al., GS-8, this volume) is similar to iron formation (P1) at the base of the Pipe Formation in the TNB.

The dark grey to brown, siliceous schist and gneiss that host the iron formation have thin primary layering defined by variations in biotite content. The average garnet content is generally <10% and the grains are

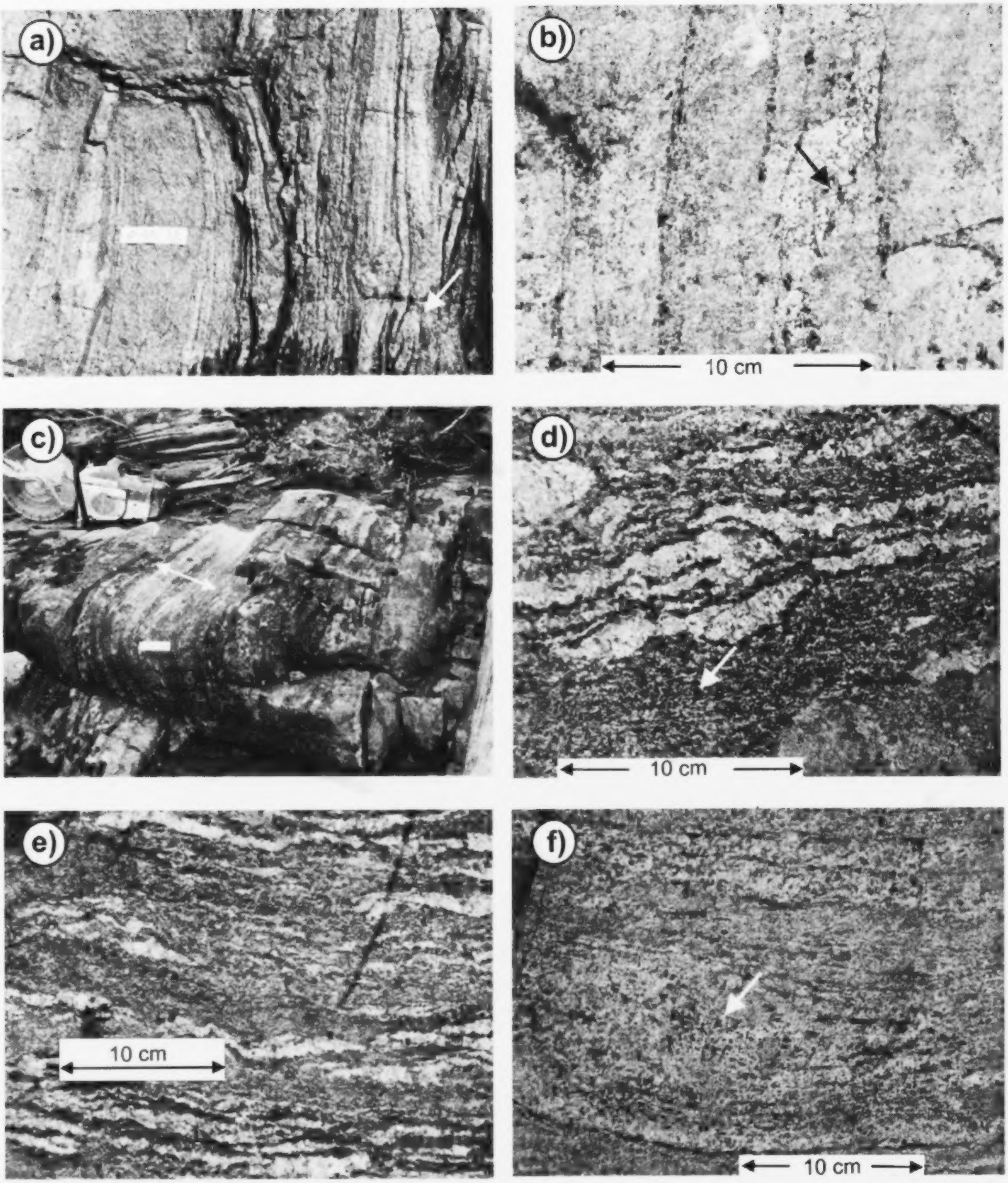

Figure GS-9-3: *Typical units in the Wuskwatim Lake area, northeastern Kisseynew Domain:* ***a)*** *layered multicomponent biotite-granulite gneiss, showing local isoclinal intrafolial folds (arrow); tape is 10 cm long;* ***b)*** *arkosic quartzite with thin biotite-rich partings as remnants of bedding and yielding only Archean detrital zircons; note pegmatite at arrow; c) sulphide-facies iron formation with quartz-rich garnet-biotite gneiss interlayer (arrow);* ***d)*** *quartz-rich veins in biotite-garnet gneiss, similar to photo (e) but formed from Archean detritus; garnets (arrow) are dark;* ***e)*** *Burntwood Group greywacke-mudstone-derived metatexite with quartz-rich leucosome; and* ***f)*** *calcareous quartz-rich metapsammite with lenses (near scale bar) and layers of calcsilicate minerals (top) including calcite.*

<3 mm in diameter in all but some of the iron-rich layers. Sillimanite±muscovite is a prominent component in sparse pelitic beds near the top and bottom of the unit. The rock is locally sulphidic and graphitic. It includes garnet-rich and mafic layers of silicate-facies iron formation that are on the order of 50 cm thick. Other prominent interbeds are very quartz rich and probably derived from impure chert. Veins of leucosome contain mainly quartz in this rock type. Layers or lenses of calcsilicate rock are locally present.

There are metagabbro layers elsewhere in the unit. If the correlation with the lower Pipe formation is valid, this is the most likely stratigraphic level for ultramafic sills and nickel deposits.

Biotite-garnet gneiss

This garnet-rich rock, which is the highest in the exposed section, forms a thin unit structurally overlain by the Burntwood Group. It is a grey-weathering pelitic unit that contains up to 25% garnet porphyroblasts. One locality has a layer with 50% garnet, up to 8 mm in diameter. Otherwise, the rock is generally uniform, with only rare 8 cm beds containing smaller garnets than normal. The rock has 20 to 40% quartz-feldspar leucosome or quartz veins (Figure GS-9-3d).

Burntwood Group

The Burntwood Group is the most widespread unit in the northeastern part of the KD. It forms a monotonous succession of medium grey– to reddish brown–weathering, turbidite-derived greywacke-mudstone migmatite. This unit is typically graphitic and magnetite free with only rare pyrrhotite; as a consequence, it provides a magnetically quiet background in the Wuskwatim Lake corridor. In the field, however, it can be mistaken for units in the heterogeneous paragneiss succession or some units in the Ospwagan Group (Zwanzig and Böhm, 2002).

In the Wuskwatim Lake area, primary bedding has been structurally transposed and metamorphosed into migmatite layering. Remnants of bedding are best defined by garnet size: 2 to 3 mm in the psammitic lower parts of the beds and up to 10 mm (10–20%) in the upper pelitic parts of the beds. The biotite- and garnet-rich metapelite can contain abundant K-feldspar. Granitoid leucosome in the normal stromatic migmatite (metatexite) constitutes 10 to 50% of the rock in lits that have a local maximum thickness of 2 to 50 cm (Figure GS-9-3e). The leucosome in the Wuskwatim Lake area is unusual in that it contains abundant garnet and commonly large cordierite porphyroblasts ±sillimanite ±orthopyroxene ±spinel. Less common diatexite has lost all primary structure during transformation to 60 to 90% coarse crystal–charged partial-melt rock.

Calcareous psammite

Isotopic analyses presented later in this paper show that, adjacent to the heterogeneous paragneiss, the Burntwood Group contains an unusual formation of quartz-rich calcareous psammitic gneiss. This light grey–weathering, highly felsic rock shows remnants of bedding and lamination defined by increased biotite content (Figure GS-9-3f). The unit is about 10 m thick on Wuskwatim Lake, where it occurs between the greywacke migmatite and the unrelated biotite-garnet gneiss. The directly overlying rocks to the northwest are relatively garnet rich and more uniformly pelitic than elsewhere. About 150 m of the same calcarious psammite occur also in the southeast-facing section south of the widened Burntwood River. This thicker unit contains more interbedded garnet-biotite gneiss with quartz-rich leucosome.

Correlation with Ospwagan Group stratigraphy

The lithology of several units in the Wuskwatim Lake corridor resembles that in the lower part of the Ospwagan Group in the TNB (Figure GS-9-2):

- The multicomponent orthogneiss may be equivalent to the TNB basement gneiss (but its age of crystallization has yet to be determined).
- The arkosic quartzite resembles the M1 member of the Manasan Formation and, if the proposed unconformity is confirmed by geochronology, would be the same as the unconformity at the base of the Manasan Formation in the TNB.
- A thin layer of diopside gneiss stratigraphically above the quartzite may represent a calcsilicate layer correlative with part of the Thompson Formation in the TNB.
- The garnet-biotite gneiss and sulphide-facies iron formation and overlying biotite-garnet gneiss are similar to the P1 and P2 members in the Pipe Formation. Garnet is much more abundant and sillimanite is scarce, but this may be a result of the higher metamorphic grade.

The general structural stacking order of units is similar to that in the TNB, with Burntwood overlying the older rocks. In the Wuskwatim paragneiss succession, however, several units are lacking and there may be an extra unit in the Burntwood Group:

- A full equivalent to the Thompson Formation that includes marble is not found in the heterogeneous paragneiss succession on Wuskwatim Lake or the Burntwood River to the north. The only calcareous rock appears to be a thin diopside gneiss layer. A thicker, weakly calcareous unit, which occurs higher in the structural stack, is associated with the allochthonous Burntwood Group. This is a serious problem in the correlation because the calcsilicate and marble are the best marker units in the Ospwagan Group.

Nevertheless, calcsilicate rocks that look similar to the Thompson Formation were found on a reconnaissance into Kawaweyak Lake (Percival et al., GS-8, this volume). These occur adjacent to prominent sulphide-facies iron formation in a presently unknown stratigraphic order. The carbonate is generally low weathering and may simply not be exposed in most areas.

- The prominent M2 member (Pipe Formation pelite) is seen only locally, but this may be due to lack of exposure of this unit, which also weathers recessively.
- The presence of calcareous quartz-rich paragneiss in the Burntwood Group is unusual with respect to the group's regional composition. This unit is possibly part of a different tectonic assemblage.
- The upper part of the section is missing and basement is missing in some areas, but this can be explained by faulting.

Thus, at the current state of understanding, each argument for or against correlation can be countered with an ad hoc explanation.

In order to test the proposed correlation more rigorously, geochemistry and Nd isotope geology are applied. These methods have been used successfully in mapping the northern extent of the TNB (Zwanzig and Böhm, 2002, 2004; Zwanzig et al., work in progress, 2006). Some preliminary results obtained using this technique at Wuskwatim Lake are discussed below.

Geochemistry and isotope geology

Significant differences in the source area of the detritus for the Ospwagan Group and younger arc-related rocks (Burntwood, Grass River and Sickle groups) have provided a useful geochemical distinction between these different assemblages of clastic rocks (Zwanzig et al., work in progress, 2006). They can be distinguished using geochemical diagrams of selected major and trace elements, normalized by the average composition of the most widespread pelitic unit in the TNB, the P2 member of the Pipe Formation. This technique is applied to the heterogeneous paragneiss assemblage at Wuskwatim Lake using data fields from the TNB for comparison.

Routine sampling with sledge hammers was carried out during the mapping and important units were cut by saw on shore outcrops. Samples were crushed in mild steel and given standard analysis using x-ray fluorescence (XRF) for major elements and inductively coupled plasma mass spectrometry (ICP-MS) for trace elements to provide a complete geochemical fingerprint. The work was done to 'standard' precision at Activation Laboratories Ltd. in Ancaster, Ontario, and data are presented in Table GS-9-1, along with existing analyses from the TNB taken from Zwanzig et al. (work in progress, 2006) and D. Peck (pers. comm., 2003).

Fields of existing data from Ospwagan Group sedimentary rocks in the TNB and Burntwood Group paragneiss collected regionally in the KD (Figures GS-9-4a, -4b) are compared to multi-element plots of paragneiss from Wuskwatim Lake (Figure GS-9-4c, -4f). Amphibolite is compared to a primitive-mantle-normalized field of plots from synkinematic dikes and similar amphibolite from the TNB margin and elsewhere in the KD (Figure GS-9-4g).

The plots suggest that parts of the section of heterogeneous high-grade metasedimentary rocks on Wuskwatim Lake share geochemical characteristics with the Ospwagan Group. Other parts of the section may have a volcanic-arc-related provenance with some similarity to the Burntwood Group, rather than the typical Archean craton–derived Ospwagan Group. Particularly indicative of an arc-related provenance are the prominent negative Zr and K anomalies that are typical of all arc assemblages, including those in the Paleoproterozoic Trans-Hudson Orogen and in the Archean Superior Province. The positive slope from the large ion lithophile elements (LILE) to heavy rare earth elements (HREE) of the P2-normalized analyses (Figure GS-9-4c) is inconsistent with provenance from the peneplaned Archean Superior craton that was the source of the Ospwagan Group and produced a flat P2-normalized plot (Zwanzig et al., work in progress, 2006). The higher P_2O_5 contents are also typical of Kisseynew basin compositions (Figure GS-9-4d). The plots resemble light rare earth element– and alkali element–depleted basement orthogneiss and 'anomalous' paragneiss in the northern extension of the TNB (Figure GS-9-4e). A sample of diopside calcsilicate gneiss has the immobile element pattern of more aluminous but otherwise similar rock from the Thompson Formation in the TNB (Figure GS-9-4f). Samples of Thompson diopside calcsilicate that have the same low Al_2O_3 content as the unit northwest of Wuskwatim Lake also have the same low alkali element content and similar low contents of V, Cr and Ni (Table GS-9-1) typical of continent-derived sedimentary rocks. An amphibolite body in the Burntwood Group is similar to synkinematic diabase dikes elsewhere in the KD (Figure GS-9-4g)

Based on bulk chemical characteristics alone, possible alternative sediment sources may include provenance from

1) the Superior craton, which provides a link with the Ospwagan Group, but this is not well expressed;
2) the juvenile internal zone of Trans-Hudson Orogen, which also fed the Burntwood Group;
3) Archean rocks that are known to exist locally in parts of the internal zone, based on the presence of contaminated arc-volcanic rock;
4) older, more depleted Archean basement occurring in the northern extension of the TNB, where it retains much of its arc signature but may have lost Th, U,

Table GS-9-1: Analytical data for rock samples from Wuskwatim Lake in the northeastern Kisseynew Domain and, for comparison, from the Thompson Nickel Belt (Zwanzig et al., work in progress, 2006).

Sample	12-06-31-3	12-06-31-4	12-06-34-1	12-06-43-1	12-06-43-3	12-06-43-5	12-06-43-6	12-06-42-1	PBA04-18	38-88-12	38-88-14	SP-02-02B	98-46
Rock type	Intermediate granulite	Felsic gneiss	Garnet-biotite gneiss	Garnet-biotite gneiss	Psammite + calcite	Biotite-garnet gneiss	Biotite-garnet gneiss	Amphibolite	Calc-silicate	*Diopside gneiss	*Skarn (calc-silicate)	*Skarn + diopside	Mg-rich gabbro dike
Area	Wuskwatim	Wuskwatim	Wuskwatim	Wuskwatim	Wuskwatim	Wuskwatim	Wuskwatim	Wuskwatim	Wuskwatim	Pipe 2 pit	Pipe 2 pit	Thompson S pit	Minago River
Unit	Orthogneiss		?	Burntwood Gp		Ospwagan-like		Dike?	T?	Thompson Formation			Molson
SiO$_2$	66.17	68.04	66.89	59.14	76.58	68.55	56.46	49.28	50.00	50.40	55.70	51.22	50.91
Al$_2$O$_3$	16.13	15.88	14.56	16.19	9.11	11.40	17.95	12.90	6.00	2.77	4.21	12.65	5.83
Fe$_2$O$_3$	3.72	3.21	4.79	12.13	2.77	11.18	12.39	15.12	2.50	3.85	1.84	4.02	7.85
MnO	0.04	0.03	0.06	0.40	0.03	0.15	0.14	0.25	0.05	0.09	0.05	0.08	0.15
MgO	1.99	1.17	2.81	4.00	1.27	3.17	3.89	4.73	14.50	15.20	14.01	10.14	16.87
CaO	3.76	3.03	2.60	2.07	4.91	1.50	2.53	12.11	22.40	23.42	20.28	12.64	17.18
Na$_2$O	3.62	4.35	2.95	2.59	0.59	0.90	2.87	1.41	0.10	0.21	0.21	0.31	0.59
K$_2$O	2.64	2.95	4.31	1.82	0.78	1.89	2.18	0.14	0.70	0.40	2.92	5.33	0.12
TiO$_2$	0.50	0.46	0.53	1.15	0.30	0.99	1.23	2.48	0.51	0.15	0.17	0.50	0.48
P$_2$O$_5$	0.17	0.12	0.19	0.08	0.08	0.09	0.05	0.25	0.09	0.23	0.05	0.08	0.03
LOI	1.55	1.13	0.66	-0.34	3.02	0.80	0.08	1.01	2.20	3.59	1.00	2.86	3.92
Total	100.3	100.4	100.3	99.2	99.4	100.6	99.8	99.7	96.9	96.7	99.4	99.8	100.0
V	56	36	59	251	45	194	304	507	34	93	-60	44	251
Cr	40	< 20	130	220	60	160	230	70	33	25	20	44	583
Co	9	6	13	35	5	23	41	42	6			10	71
Ni	40	< 20	70	80	< 20	80	120	50	<10	18	9	<20	241
Cu	50	< 10	10	20	20	30	20	310	13	7	8	<10	315
Zn	40	50	70	120	60	90	120	110	96	216	157	67	35
Ga	21	21	20	22	10	16	24	23	9			16	
Ge	< 1	1	1	2	1	2	3	2				2	
Rb	57	57	122	81	46	73	98	1	48	12	26	111	3
Sr	555	301	250	130	119	60	149	245	58	57	55	105	
Y	9.0	8.0	25.0	26.0	15.0	23.0	28.0	48.0	15.0			19.0	15.3
Zr	205	292	148	138	77	169	107	166	117			167	27
Nb	6.0	6.0	11.0	8.0	3.0	7.0	8.0	11.5	17			8.5	<1
Sb	0.9	1.4	14.5	< 0.5	4.3	3.1	16.1	7.6	-0.2			0.3	
Cs	< 0.5	< 0.5	< 0.5	1.0	< 0.5	1.3	0.9	0.1	0.6			2.1	
Ba	1467	1446	969	481	863	367	339	42	216	85	216	749	19
La	42.70	96.40	42.80	21.60	15.70	23.30	18.30	9.69	22.00			31.43	7.52

Table GS-9-1: Analytical data for rock samples from Wuskwatim Lake in the northeastern Kisseynew Domain and, for comparison, from the Thompson Nickel Belt (Zwanzig et al., work in progress, 2006). *(continued)*

Sample	**12-06-31-3**	**12-06-31-4**	**12-06-34-1**	**12-06-43-1**	**12-06-43-3**	**12-06-43-5**	**12-06-43-6**	**12-06-42-1**	**PBA04-18**	**38-88-12**	**38-88-14**	**SP-02-02B**	**98-46**
Rock type	Intermediate granulite	Felsic gneiss	Garnet-biotite gneiss	Garnet-biotite gneiss	Psammite + calcite	Biotite-garnet gneiss	Biotite-garnet gneiss	Amphibolite	Calc-silicate	*Diopside gneiss	*Skarn (calc-silicate)	*Skarn + diopside	Mg-rich gabbro dike
Area	Wuskwatim	Wuskwatim	Wuskwatim	Wuskwatim	Wuskwatim	Wuskwatim	Wuskwatim	Wuskwatim	Wuskwatim	Pipe 2 pit	Pipe 2 pit	Thompson S pit	Minago River
Unit	Orthogneiss		?	Burntwood Gp		Ospwagan-like		Dike?	T?			Thompson Formation	Molson
Ce	73.20	172.00	86.50	49.20	30.10	44.70	41.30	26.10	38.00			57.49	19.96
Pr	7.32	17.40	9.49	5.85	4.00	5.22	4.92	4.08	4.50			6.44	3.00
Nd	22.70	52.80	32.20	20.40	14.30	18.30	18.00	20.40	17.00			25.16	15.07
Sm	3.90	7.90	6.40	4.60	3.10	3.90	4.30	6.02	3.00			4.16	4.40
Eu	1.62	1.68	1.15	1.30	1.06	0.94	1.56	2.10	0.53			0.96	1.16
Gd	2.20	4.10	5.30	4.20	2.70	3.70	4.10	7.18	2.50			3.94	3.73
Tb	0.30	0.50	0.80	0.80	0.40	0.70	0.80	1.32	0.36			0.56	0.56
Dy	1.70	1.90	4.70	4.60	2.60	4.00	4.70	8.25	2.20			3.02	2.91
Ho	0.30	0.30	0.90	0.90	0.50	0.80	1.00	1.67	0.45			0.60	0.55
Er	0.90	0.70	2.30	2.70	1.40	2.40	2.90	4.87	1.20			1.79	1.42
Tm	0.13	0.09	0.30	0.41	0.20	0.37	0.44	0.70	0.19			0.28	0.18
Yb	0.80	0.60	1.80	2.70	1.30	2.40	3.10	4.58	1.30			1.70	1.13
Lu	0.12	0.09	0.26	0.43	0.20	0.37	0.49	0.69	0.18			0.25	0.15
Hf	4.80	7.50	4.10	3.70	2.10	4.60	3.00	4.60	3.30			4.62	1.07
Ta	0.20	0.20	0.50	0.50	0.30	0.40	0.40	0.79	1.10			0.83	0.40
Tl	0.30	0.30	0.70	0.30	0.30	0.30	0.50	< 0.05	0.30			0.57	
Pb	21.00	21.00	27.00	12.00	20.00	9.00	11.00	< 5	3.00			5.25	
Th	8.40	36.40	18.50	5.80	3.20	8.60	3.80	0.30	4.90			11.80	0.28
U	0.60	0.80	0.80	1.30	1.40	0.60	0.80	0.23	3.10			1.38	0.20

*** unpublished data for comparison**
Major elements in weight percent, trace elements in ppm.

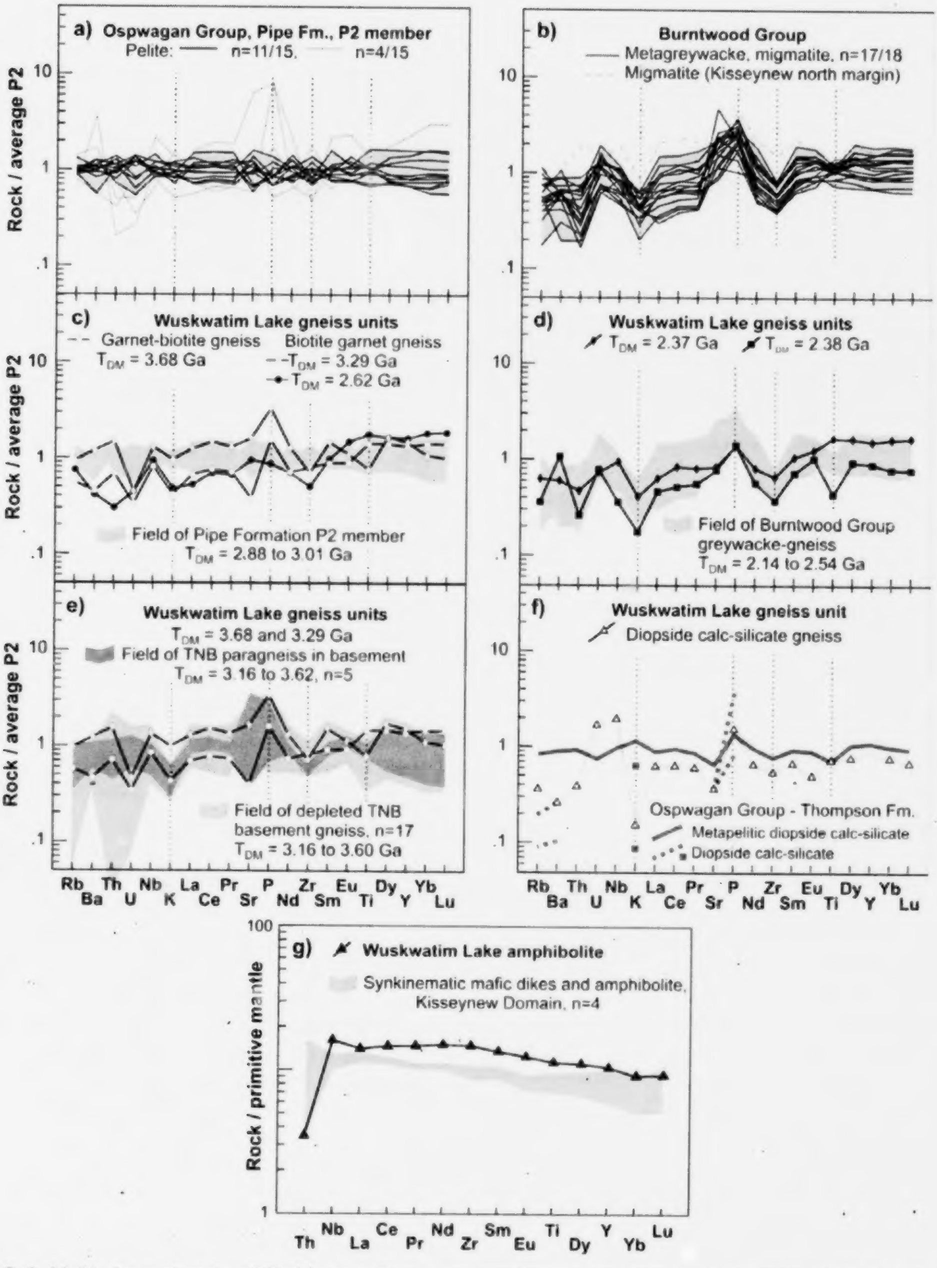

Figure GS-9-4: *Multi-element plots of Ospwagan Group sedimentary rocks from the Thompson Nickel Belt and Burntwood Group from the Kisseynew Domain (plots a, b), Wuskwatim Lake (plots c–f), and primitive-mantle-normalized amphibolite units compared to an analysis from Wuskwatim Lake (plot g):* ***a)*** *the most abundant pelite (P2 member) in the TNB, normalized with the average of the 11 most common of its own compositions (highlighted field) out of a total of 15 analyses (outliers in grey lines);* ***b)*** *Burntwood Group (P2 normalized), showing all but outliers in highlighted field;* ***c)*** *pelitic gneiss from Wuskwatim Lake (P2 normalized) compared to the field of P2;* ***d)*** *garnet-biotite gneiss and calcareous quartz-rich gneiss (P2 normalized) compared to the field of the Burntwood Group;* ***e)*** *pelitic gneiss with high Nd model ages (T_{DM}) from Wuskwatim Lake (P2 normalized) compared to the fields of depleted basement gneiss from the TNB (pale shade) and to 'anomalous' paragneiss from the outer margins of the TNB (dark grey);* ***f)*** *diopside calcsilicate gneiss (P2 normalized) compared to plots of three isolated beds of similar rock in the Thompson Formation, one bed relatively pelitic (solid grey line) and two partly analyzed beds (dotted partial lines) with similar major-element geochemistry to the diopside calcsilicate;* ***g)*** *amphibolite from the analyzed section on Wuskwatim Lake (primitive-mantle normalized) compared to the field of synkinematic diabase sheets and equivalent amphibolite from the TNB margin and elsewhere in the KD.*

and K during deep crustal metamorphic processes (Figure GS-9-4e); and

5) various terranes providing a mixture of detritus.

More information is clearly required to distinguish these possibilities. Some of this has been provided by preliminary Nd isotope data and one recalculated detrital zircon spectrum.

Seven new samples were analyzed for Nd isotope ratios at the University of Alberta geochronology laboratory (Table GS-9-2). The data were used to calculate depleted-mantle model ages of mantle-crust separation (for an explanation of this method, *see* Zwanzig and Böhm, 2002). The Nd model (T_{CHUR}) ages are also given in Figure GS-9-4, where they divide the six sedimentary samples into three groups: those with Mesoarchean model ages, one with a late Neoarchean model age and those with Paleoproterozoic model ages. The youngest set is interpreted as part of the Burntwood Group or as sedimentary rocks with a similar provenance (Figure GS-9-4d), consistent with alternative 2 (above). Surprisingly, this includes the calcareous quartz-rich unit that is not generally part of the Burntwood Group and was initially thought to be correlative with the Thompson Formation.

Rocks with Mesoarchean model ages may have a provenance in Mesoarchean basement rocks on the northern margin of the TNB (Zwanzig and Böhm, 2004) and apparently in deeply exposed crust, such as in the core of the dome containing the Mel zone and near Orr Lake (Figure GS-9-1; Zwanzig and Böhm, 2002, 2004). Such paragneiss units also occur on the periphery of the TNB (near the Birchtree mine and on Paint Lake) and interlayered with the orthogneiss basement (at the Soab mine and east of Strong Lake). These samples are consistent with alternative 4 (above), but do not distinguish between an Archean and a Proterozoic age of deposition (discussed later in the paper). The deeper seated, chemically similar basement also has the same range of Nd model ages as the pelite on Wuskwatim Lake (Figure GS-9-4e). Additional clues to the origin of these rocks are provided by detrital zircon ages (below).

The two samples with young model ages are clearly Proterozoic and consistent with alternative 2 (Figure GS-9-4d). One sample of garnet-biotite gneiss with a model age of 2.62 Ga may have a mixed provenance consistent with alternative 5.

Detrital zircon ages

Preliminary detrital zircon results for an arkosic quartzite from the section on the Burntwood River northwest of Wuskwatim Lake (Geological Survey of Canada lab number 8334) were reported in Percival et al. (2005). Initial results, which indicated exclusively Archean zircons, were based on a very small dataset (n = 5) derived from grains that gave reproducible sensitive high-resolution ion microprobe (SHRIMP) results. Most of the grains analyzed (n = 26) were considered unreliable due to either nonreproducible replicates within individual grains or very significant signal variations during a single analysis, leading to extremely large analytical uncertainties. The difficulty of within-analysis analytical scatter has been overcome by processing the raw data using the SQUID program (Ludwig, 2001), which employs a robust regression method (two-peak interpolations) that is less sensitive to outliers. Using this method, the authors were able to present the entire set of results (Table GS-9-3, Figure GS-9-5).

The difficulty of nonreproducible ages remains: of the nine grains where replicate analyses were carried out, only four have reproducible ages. The $^{207}Pb/^{206}Pb$ ages range from 2325 to 3328 Ma, and a significant number are greater than 5% discordant. If a zircon is concordant or nearly so, its $^{207}Pb/^{206}Pb$ age represents the age of the detritus; however, for discordant analyses, the $^{207}Pb/^{206}Pb$ age can only be considered a minimum. Only zircons less than 5% discordant are plotted on the histogram and shown as the light grey cumulative probability curve (Figure GS-9-5b). Excluded from this dataset are replicate, concordant results; in these instances, the oldest of the replicates was plotted. For reference, the entire dataset, regardless of concordance and including replicate analyses, is shown by the dark grey cumulative probability curve. The concordant results indicate a well-defined mode at 2.7 Ga (n = 6), sporadic values between 2.8 and 3.2 Ga (n = 8) and another mode at 3.3 Ga (n = 7). Despite the fact that they are concordant, it is possible that replicate analyses on the grains in the 2.8 to 3.2 Ga range would not give reproducible ages due to Pb loss. Therefore, these ages should not necessarily be considered a representative age of detritus. The cluster of results at 2.7 Ga and ca. 3.3 Ga would indicate that these are meaningful populations. This expanded dataset supports the conclusion of Percival et al. (2005) that the detrital population of sample 8334 is broadly similar to that of the Ospwagan Group, in that it is exclusively Archean in age. Nevertheless, the prevalence of very ancient zircons in this sample is distinct from other samples. Detrital studies of the Pipe Formation (sample 7798) and the Thompson pelite (sample 8422) have not uncovered any zircons older than 2.95 Ga (Rayner et al., GS-11, this volume). Hamilton and Bleeker (2002) reported only one zircon grain older than 2.85 Ga (3150 Ma). More than half of the concordant zircons from sample 8334 are older than 3.1 Ga and roughly one-third are ca. 3.3 Ga.

Although they are derived from the basal quartzite of the heterogeneous paragneiss succession, these detrital ages are consistent with alternative 4 suggested by the geochemical data.

Table GS-9-2: Sm-Nd analytical data from the Wuskwatim Lake area, northeastern Kisseynew Domain.

Sample	Sm (ppm)	Nd (ppm)	$^{147}Sm/^{144}Nd$	$^{143}Nd/^{144}Nd$	Uncert. (±2σ)	T_{DM}	$\sim T_{Ma}$	ε_{NdT}	$^{145}Nd/^{144}Nd$	Rock type	Area	Easting	Northing	Comment
12-06-31-3	3.07	19.72	0.094	0.511	0.000	3.15	1900	-13.3	0.348	Intermediate granulite	Burntwood R.	528822	6164551	Paragneiss
12-06-31-4	6.03	44.27	0.082	0.510	0.000	3.27	2700	-5.5	0.348	Felsic gneiss	Burntwood R.	528822	6164551	Basement(?)
12-06-34-1	5.69	29.07	0.118	0.511	0.000	3.68	1900	-16.0	0.348	Garnet-biot. gneiss+Su	Burntwood R.	526263	6163968	Prob. Pipe Fm.
12-06-43-1	4.00	19.24	0.126	0.512	0.000	2.37	1900	0.7	0.348	Garnet-biotite gneiss	Wuskwatim L.	529097	6161648	Burntwood Gp.
12-06-43-3	2.71	13.53	0.121	0.512	0.000	2.38	1900	0.3	0.348	Calcsilicate	Wuskwatim L.	529097	6161648	Burntwood Gp.(?)
12-06-43-5	2.91	13.27	0.133	0.511	0.000	3.29	1900	-8.6	0.348	Biotite-garnet gneiss	Wuskwatim L.	529092	6161646	Poss. Pipe Fm.
12-06-43-6	3.30	14.71	0.136	0.512	0.000	2.62	1900	-1.1	0.348	Biotite-garnet gneiss	Wuskwatim L.	529097	6161648	Uncertain affinity

Table GS-9-3: Sensitive high-resolution ion microprobe (SHRIMP) U-Pb data for zircon from arkosic quartzite (Geological Survey of Canada lab number 8334).

Spot name	U (ppm)	Th (ppm)	$\frac{Th}{U}$	Pb* (ppm)	^{204}Pb (ppb)	$\frac{^{204}Pb}{^{206}Pb}$	$\pm\frac{^{204}Pb}{^{206}Pb}$	$f(206)^{204}$	$\frac{^{208}Pb^*}{^{206}Pb^*}$	$\pm\frac{^{208}Pb}{^{206}Pb}$	$\frac{^{207}Pb^*}{^{235}U}$
Grains with reproducible replicates:											
8334-57.1	65	107	1.7	45	14	52.24E-	10.64E-	0.009	0.467	0.005	11.910
8334-57.2	86	154	1.8	73	21	51.94E-	71.35E-	0.008	0.527	0.008	13.998
8334-114.1	84	49	0.6	67	1	14.65E-	16.65E-	0.000	0.158	0.002	25.739
8334-114.2	105	84	0.8	87	13	22.44E-	43.65E-	0.003	0.222	0.004	23.737
8334-124.1	110	57	0.5	90	2	24.85E-	30.45E-	0.000	0.144	0.002	25.541
8334-124.2	121	47	0.4	87	3	42.15E-	13.95E-	0.000	0.107	0.002	22.687
8334-103.1	68	122	1.9	50	10	36.14E-	91.05E-	0.006	0.533	0.008	12.698
8334-103.2	80	151	2.0	53	16	52.74E-	12.54E-	0.009	0.552	0.009	11.530
Grains with non-reproducible replicates:											
8334-98.1	362	305	0.9	267	10	53.85E-	10.15E-	0.000	0.240	0.001	20.509
8334-98.2	448	108	0.3	292	14	61.35E-	14.25E-	0.001	0.070	0.001	19.556
8334-122.1	50	80	1.7	41	2	81.25E-	35.55E-	0.001	0.447	0.005	15.704
8334-122.2	88	150	1.8	72	10	23.34E-	55.15E-	0.004	0.498	0.006	16.010
8334-118.1	101	49	0.5	79	1	14.25E-	14.05E-	0.000	0.130	0.002	24.304
8334-118.2	33	12	0.4	18	15	11.43E-	20.14E-	0.019	0.109	0.004	13.949
8334-59.1	129	116	0.9	62	8	18.84E-	45.15E-	0.003	0.268	0.003	7.856
8334-59.2	77	71	1.0	39	9	35.04E-	74.05E-	0.006	0.253	0.005	8.972
8334-59.3	98	79	0.8	51	15	41.14E-	65.25E-	0.007	0.237	0.004	11.164
8334-64.1	135	92	0.7	65	1	14.85E-	23.06E-	0.000	0.205	0.002	8.392
8334-64.2	56	45	0.8	38	4	15.14E-	28.75E-	0.002	0.224	0.004	19.075
Grains without replicates:											
8334-109.1	132	177	1.4	97	7	11.84E-	33.85E-	0.002	0.399	0.008	15.180
8334-110.1	185	101	0.6	121	11	13.44E-	22.75E-	0.002	0.148	0.004	15.523
8334-116.1	137	72	0.5	101	1	18.65E-	19.25E-	0.000	0.142	0.001	23.185
8334-117.1	156	80	0.5	93	4	65.95E-	24.05E-	0.001	0.156	0.002	13.606
8334-119.1	103	134	1.3	83	2	39.05E-	76.86E-	0.000	0.368	0.003	20.903
8334-123.1	182	181	1.0	105	10	14.14E-	29.35E-	0.002	0.283	0.004	11.050
8334-21.1	61	56	1.0	40	3	98.75E-	48.35E-	0.001	0.267	0.007	13.309
8334-24.1	66	40	0.6	51	17	48.04E-	77.15E-	0.008	0.172	0.005	21.617
8334-25.1	49	22	0.5	37	17	61.64E-	93.45E-	0.010	0.123	0.002	23.455
8334-26.1	270	101	0.4	124	16	16.94E-	34.05E-	0.002	0.111	0.002	9.994
8334-27.1	73	96	1.4	54	14	44.04E-	92.05E-	0.007	0.393	0.004	13.390
8334-36.1	60	61	1.0	41	16	56.54E-	88.15E-	0.009	0.262	0.008	14.030
8334-44.1	130	143	1.1	72	11	24.44E-	43.25E-	0.004	0.311	0.003	9.927
8334-44.1	140	117	0.9	107	14	19.74E-	40.85E-	0.003	0.238	0.002	21.064
8334-55.1	83	72	0.9	52	13	36.24E-	65.25E-	0.006	0.236	0.004	14.196
8334-58.1	86	38	0.5	62	10	20.64E-	39.35E-	0.003	0.113	0.004	22.891
8334-60.1	119	195	1.7	80	8	16.94E-	44.25E-	0.002	0.487	0.004	11.841
8334-65.1	74	111	1.6	53	2	70.45E-	31.25E-	0.001	0.417	0.011	13.543
8334-70.1	30	41	1.4	23	7	54.94E-	14.94E-	0.009	0.435	0.011	15.510
8334-89.1	40	51	1.3	38	10	42.24E-	88.15E-	0.007	0.348	0.004	24.987
8334-91.1	67	86	1.3	63	8	20.54E-	53.75E-	0.003	0.337	0.003	27.105
8334-92.1	141	124	0.9	110	11	14.74E-	23.25E-	0.002	0.249	0.004	20.671

Notes (see Stern, 1997):

* refers to radiogenic Pb (corrected for common Pb)

Spot name follows the convention x-y.z; where x = sample number, y = grain number and z = spot number.

Uncertainties reported at 1σ (absolute) and are calculated by numerical propagation of all known sources of error

$f(206)^{204}$ refers to mole fraction of total ^{206}Pb that is due to common Pb, calculated using the ^{204}Pb method; common Pb composition used is the surface blank (4/6: 0.05770; 7/6: 0.89500; 8/6: 2.13840)

(cont.)

Table GS-9-3: Sensitive high-resolution ion microprobe (SHRIMP) U-Pb data for zircon from arkosic quartzite (Geological Survey of Canada lab number 8334). *(continued)*

Spot name	$\pm\frac{^{207}\text{Pb}}{^{235}\text{U}}$	$\frac{^{206*}\text{Pb}}{^{238}\text{U}}$	$\pm\frac{^{206}\text{Pb}}{^{238}\text{U}}$	Corr. Coeff.	$\frac{^{207*}\text{Pb}}{^{206}\text{Pb}^*}$	$\pm\frac{^{207}\text{Pb}}{^{206}\text{Pb}}$	Apparent ages (Ma) $\frac{^{206}\text{Pb}}{^{238}\text{U}}$	$\pm\frac{^{206}\text{Pb}}{^{238}\text{U}}$	$\frac{^{207}\text{Pb}}{^{206}\text{Pb}}$	$\pm\frac{^{207}\text{Pb}}{^{206}\text{Pb}}$	Disc. (%)
Grains with reproducible replicates											
8334-57.1	0.228	0.470	0.007	0.827	0.235	0.002	2484	33	2687	18	8.2
8334-57.2	0.378	0.543	0.008	0.558	0.249	0.002	2795	34	2716	37	-2.8
8334-114.1	0.457	0.692	0.012	0.964	0.184	0.002	3390	45	3305	7	-2.5
8334-114.2	0.368	0.636	0.009	0.944	0.273	0.004	3172	37	3311	8	4.4
8334-124.1	0.469	0.687	0.011	0.882	0.246	0.001	3370	43	3305	14	-1.9
8334-124.2	0.621	0.615	0.017	0.985	0.246	0.001	3091	66	3291	7	6.5
8334-103.1	0.294	0.501	0.008	0.669	0.148	0.002	2617	33	2688	28	2.7
8334-103.2	0.387	0.433	0.011	0.755	0.218	0.004	2319	49	2769	36	19.4
Grains with non-reproducible replicates											
8334-98.1	0.286	0.605	0.008	0.938	0.173	0.001	3052	32	3157	8	3.5
8334-98.2	0.313	0.604	0.008	0.821	0.186	0.003	3044	32	3086	15	1.4
8334-122.1	0.339	0.555	0.011	0.912	0.274	0.006	2847	45	2868	14	0.7
8334-122.2	0.275	0.545	0.009	0.918	0.239	0.003	2803	36	2930	11	4.5
8334-118.1	0.419	0.660	0.011	0.959	0.253	0.008	3268	42	3288	8	0.6
8334-118.2	0.515	0.461	0.009	0.556	0.274	0.006	2443	42	2978	49	21.9
8334-59.1	0.150	0.384	0.005	0.741	0.175	0.002	2097	25	2325	22	10.9
8334-59.2	0.315	0.410	0.011	0.749	0.185	0.002	2215	49	2442	39	10.3
8334-59.3	0.398	0.434	0.013	0.811	0.154	0.001	2323	56	2713	34	16.8
8334-64.1	0.140	0.395	0.006	0.940	0.206	0.002	2145	28	2393	10	11.6
8334-64.2	0.691	0.556	0.020	0.981	0.211	0.002	2850	82	3177	11	11.5
Grains without replicates											
8334-109.1	0.336	0.534	0.011	0.935	0.193	0.004	2757	46	2877	13	4.4
8334-110.1	0.393	0.535	0.013	0.960	0.271	0.001	2761	55	2910	11	5.4
8334-116.1	0.455	0.641	0.010	0.825	0.185	0.002	3194	41	3260	17	2.1
8334-117.1	0.327	0.508	0.008	0.660	0.202	0.002	2650	34	2777	30	4.8
8334-119.1	0.451	0.619	0.013	0.977	0.148	0.002	3107	52	3152	7	1.4
8334-123.1	0.196	0.457	0.006	0.775	0.187	0.004	2425	28	2610	19	7.6
8334-21.1	0.359	0.521	0.010	0.728	0.191	0.005	2702	43	2702	31	-0.0
8334-24.1	0.660	0.620	0.011	0.563	0.267	0.001	3110	42	3203	40	3.0
8334-25.1	0.475	0.636	0.011	0.849	0.254	0.002	3173	43	3291	17	3.7
8334-26.1	0.155	0.420	0.006	0.875	0.159	0.004	2259	26	2584	13	14.4
8334-27.1	0.409	0.518	0.013	0.815	0.253	0.008	2689	55	2722	29	1.2
8334-36.1	1.088	0.534	0.039	0.935	0.213	0.001	2758	163	2747	45	-0.4
8334-44.1	0.157	0.421	0.006	0.902	0.220	0.007	2263	27	2569	11	13.5
8334-44.1	0.398	0.602	0.010	0.895	0.235	0.002	3036	41	3210	13	5.7
8334-55.1	0.281	0.511	0.009	0.872	0.187	0.004	2659	38	2840	16	6.8
8334-58.1	0.966	0.656	0.017	0.619	0.159	0.004	3250	67	3205	52	-1.4
8334-60.1	0.260	0.465	0.009	0.908	0.187	0.004	2462	41	2695	15	9.4
8334-65.1	0.349	0.529	0.010	0.720	0.171	0.001	2735	41	2706	30	-1.1
8334-70.1	0.627	0.516	0.019	0.913	0.253	0.006	2681	81	2967	27	10.7
8334-89.1	0.572	0.665	0.012	0.772	0.267	0.003	3285	46	3322	23	1.1
8334-91.1	0.851	0.718	0.016	0.732	0.184	0.003	3489	62	3328	33	-4.6
8334-92.1	0.427	0.628	0.011	0.853	0.188	0.003	3140	44	3112	17	-0.9

* refers to radiogenic Pb (corrected for common Pb)

Discordance relative to origin = 100 * (1-(^{206}Pb/^{238}U age)/(^{207}Pb/^{206}Pb age))

Calibration standard 6266; U = 910 ppm; Age = 559 Ma; ^{206}Pb/^{238}U = 0.09059

Error in ^{206}Pb/^{238}U calibration 1.25%

Th/U calibration: F = 0.03446*UO + 0.868

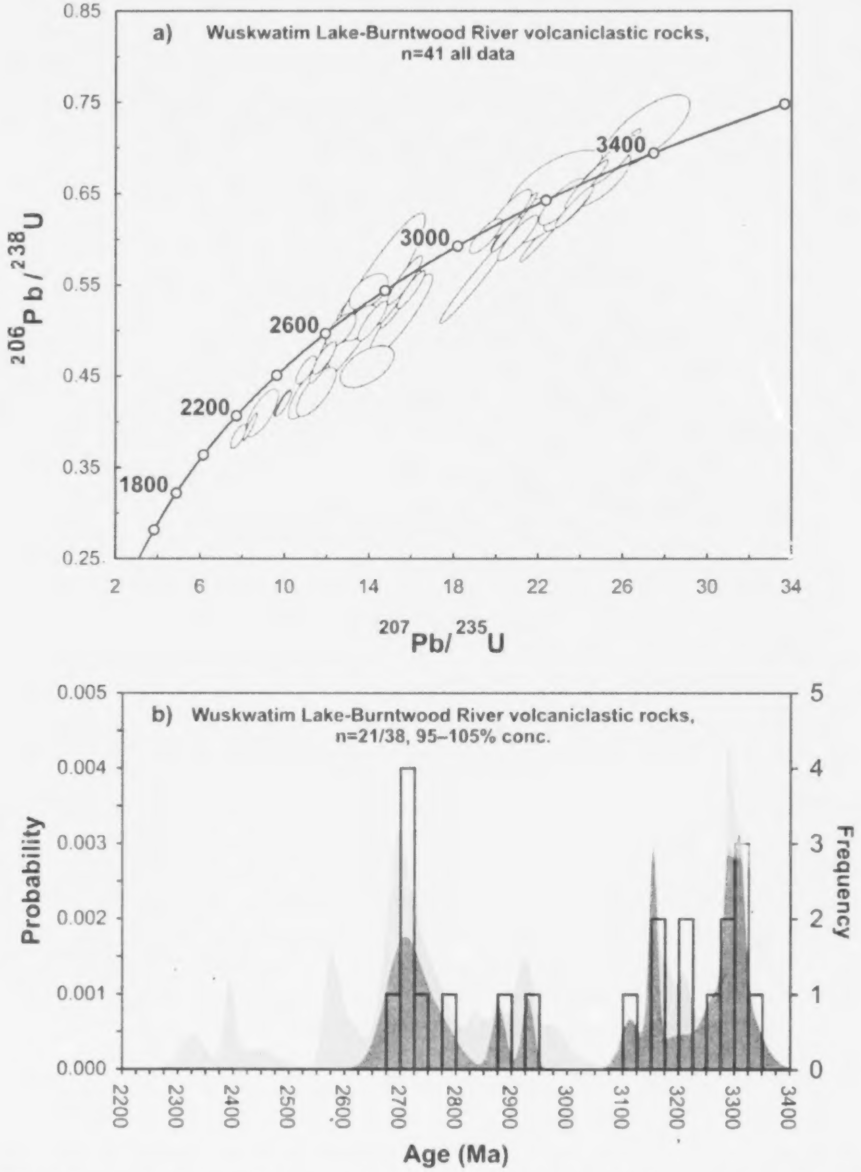

Figure GS-9-5: ***a)*** *Concordia diagram illustrating detrital zircon results for arkosic quartzite sample (Geological Survey of Canada lab number 8334). All data (n = 41), including duplicate analyses, are plotted regardless of degree of concordance. Ellipses are plotted at the 2σ uncertainty level.* ***b)*** *Cumulative probability curve and overlying histogram for detrital zircon results for sample 8334. All data (excluding concordant, duplicate results) are shown by the light grey curve. Dark grey curve and histogram are defined by data that are less than 5% discordant and do not include duplicates (n = 21).*

Discussion

Field and laboratory work in the Wuskwatim Lake corridor since 2004 have now clearly established the presence of granitoid orthogneiss with an Archean age of crystallization and/or mantle extraction, and paragneiss with Archean detritus in the Kisseynew Domain (KD) up to 60 km west of the Thompson Nickel Belt (TNB). In the 2006 field season, an area more than 12 km long and 4 km wide was delineated in the flood-widened Burntwood River northwest of Wuskwatim Lake where the orthogneiss is interleaved with paragneiss, yielding only Archean detrital zircons and Archean Nd model ages similar to the Ospwagan Group in the TNB. Their contact is interpreted to be an unconformity. A complex domal structure underlies Wuskwatim Lake and features similar multicomponent orthogneiss with biotite-granulite mineral assemblages and Archean model ages, and similar Ospwagan-like paragneiss along its northwestern margin. Narrow belts of such heterogeneous paragneiss are traced intermittently for 40 km west-northwest past Threepoint Lake. Other such belts may lie north of Highway 391 (Percival et al., GS-8, this volume). Their origin as Archean basement gneiss is supported by their strong fabric and the presence of early mafic enclaves, as well as better preserved mafic dikes and boudins that are interpreted to be Paleoproterozoic. These are also typical features of the basement gneiss in the TNB.

The extent of Archean gneiss in the northeastern KD crust is also monitored by the distribution of granite plutons with elevated Nd model ages. These plutons occur in the KD in a 20 km wide belt that adjoins the TNB (Percival et al., 2005) and swings northwest, from Tullibee Lake possibly to Highrock Lake, 140 km west of Thompson (inset map on Figure GS-9-1). In the western part of this area, such plutons occur at Nelson House and Eyinatik Lake, 60 and 110 km west of Thompson. They range from calcalkaline granite to mildly alkaline syenite, are typically foliated and contain porphyroclastic K-feldspar. Neodymium model (T_{CHUR}) ages range from 2.3 to 2.8 Ga, and ε_{Nd} from +0.2 to –10.9 (Percival et al., 2005 and GS-8, this volume). These characteristics indicate that the granite has a significant component of melted Archean crust. Southwest of this belt, three tested plutons have nearly juvenile Proterozoic model ages (Percival et al., GS-8, this volume; Zwanzig, unpublished data, 2005). A larger population of chemically analyzed plutons (Hollings and Ansdell, 2002) has a composition similar to these juvenile plutons and unlike the bodies with long crustal residence in the northeastern KD. Whereas the plutons in the southwest have a flat aeromagnetic signature similar to the Burntwood Group country rock, bodies contaminated with or consisting of remelted Archean crust are strongly magnetic (Viljoen et al., 1999). This allows a first estimate of the extent of Archean gneiss in the crust of the northeastern KD.

At the margin of the TNB, gneissic granodiorite to porphyroclastic syenite plutons range in age from about 1890 to 1835 Ma (Zwanzig et al., 2003; Percival et al., 2004, 2005), although the younger plutons in that area are nearly juvenile and the older bodies predate the Burntwood Group. Dating these plutons in the northeastern KD will indicate when Archean crust was available for partial melting. Absolute ages are also required to clearly distinguish Archean basement orthogneiss from highly deformed Proterozoic granitoid rocks that are nearly wholesale melts of Archean crust. This is imperative in identifying TNB crust in the KD.

Based on the assumption that the multicomponent orthogneiss is largely Archean, a composite tectonostratigraphic section has been compiled from the intermittently exposed belts of heterogeneous paragneiss that are about 500 m wide and mantle the orthogneiss (Figure GS-9-2a). This section comprises basal arkosic quartzite overlain by garnet-biotite±orthopyroxene migmatite and minor calcsilicate gneiss, followed by siliceous garnet-biotite gneiss with aeromagnetically prominent sulphide-facies iron formation. This is capped by biotite-garnet gneiss and structurally overlain by the Burntwood Group. The paragneiss succession is interpreted to be derived from arkosic sandstone grading rapidly into pelite and semipelite, somewhat similar to the Manasan Formation in the TNB. The overlying gneiss, derived from minor marlstone, clay-rich siliciclastic rocks, sulphide-facies iron formation, chert and rare silicate-facies iron formation, resembles the lower part of the Pipe Formation (P1-P2) in the middle of the Ospwagan Group, possibly with a trace of underlying Thompson Formation. The marble unit (T3), which is critical for a positive correlation, was not observed. Although this could rule out an Ospwagan Group correlation, this may simply result from lack of exposure of this typically poorly exposed unit. Thus, at the present state of knowledge, the correlation with the type section in the TNB is tempting but not definitive.

A comparison of geochemical patterns and Nd model ages between the heterogeneous paragneiss and the Ospwagan Group and 'anomalous' paragneiss in the TNB has established a link between the geology at Wuskwatim Lake and the northern margin of the TNB. This comparable margin includes some belts of paragneiss near the Mel zone and others extending northeast to Pearson Lake (Figure GS-9-1). Several exploration drillcores and small outcrops in that area feature orthogneiss with Nd model ages ranging from 3.2 to 3.6 Ga (Böhm et al., work in progress, 2006). These are interlayered with or adjoin 'anomalous' paragneiss with model ages of 3.1 to 3.6 Ga, similar to the rocks on Wuskwatim Lake. Their geochemical patterns are also very similar. They have similar depletion in rare earth and low field strength elements, and slightly different geochemical anomalies compared to typical rocks of the Ospwagan Group. Adjacent belts of stratigraphically recognizable Ospwagan Group at the northern end of the TNB have model ages of 2.8 to 3.0 Ga, similar to the main part of the TNB (Böhm et al., work in progress, 2006). Thus, the presence of the Ospwagan Group is not clearly established in the Wuskwatim Lake corridor but is suggested by the association with nearly identical rocks at the north end of the TNB. The data may also be interpreted in terms of an Archean origin for some of the paragneiss at Wuskwatim Lake and in the northern TNB.

The regional structure and stratigraphic sequence at Wuskwatim Lake, however, indicate that the metasedimentary rocks are most likely Paleoproterozoic. The unconformable relationship of the basal quartzite and the wide extent of the Burntwood Group above the proposed roof thrust, subparallel to the unconformity, argue strongly for a Proterozoic age. Moreover, the abundance of garnet and dominance of sulphide-facies iron formation in the type Ospwagan Group and the 'anomalous' paragneiss in the northern TNB are similar at Wuskwatim Lake. This suggests that there may be a sedimentary facies change in the Ospwagan Group in the north and west. Sulphide facies is more abundant and carbonate facies (Thompson Formation) is weakly developed or missing. A possible explanation is that these rocks were deposited farther into the marine basin or farther down the ancient continental slope.

The Mesoarchean model ages and the detrital zircon spectrum indicate that part of the source was Mesoarchean. The similar chemical composition, model ages and detrital zircon ages of the orthogneiss and paragneiss suggest that the basement was exposed to erosion adjacent to the basin. The basement may have been more highly stretched and uplifted than that of the TNB, or completely separated into an epicontinental terrane by rifting.

If the model age of 2.6 Ga for one sample of biotite-garnet gneiss is an indication of mixing of sediments from Archean and Proterozoic sources, the heterogeneous paragneiss succession may be younger than the Ospwagan Group and have some sediments supplied from a more juvenile part of the 1880 to 1990 Ma continental or fringing arc that has been suggested by Percival et. al. (2005).

An interesting structural feature of the Wuskwatim Lake corridor is that the Burntwood Group lies on Pipe Formation–type rocks from Threepoint Lake to Wuskwatim Lake (this report) and again at the Mel zone, thus extending for 60 km if the structure is continuous (Zwanzig and Böhm, 2002). This suggests that the contact is a flat in a large thrust or the base of a thrust nappe (Zwanzig and Böhm, 2002). Along the western fault boundary of the main TNB margin, the Burntwood Group contact cuts up the footwall section from the basement gneiss west of Thompson through the Ospwagan Group near Setting Lake (Macek et al., 2006). If this structure is continuous with the early fault at Wuskwatim Lake, then the Burntwood Group was structurally emplaced from a northerly direction. The same vergence is suggested by a small thrust at the Thompson South pit (Macek et al., 2005) and by a thrust placing basement gneiss on Bah Lake assemblage (uppermost Ospwagan Group) and the Grass River Group (Zwanzig, 1999). In the northeastern KD, the 'basement' orthogneiss occurs only intermittently within the overall belt of heterogeneous paragneiss. This suggests that it may occur as megaboudins within a large D_1 thrust sheet that was highly attenuated in a midcrustal environment during D_2 and possibly thrown into a large recumbent fold before being refolded in dome-and-basin structures, as suggested for the Mel zone. Structural reconstructions will shed additional light on the question of whether the 'basement' and paragneiss 'cover' exposed in the Wuskwatim Lake corridor 1) are autochthonous beneath the northeastern KD and contiguous with the TNB and Superior Province, 2) represent a rifted epicontinental fragment, or 3) constitute the core of a nappe likely rooted to the northeast.

Economic considerations

The presence of small mafic-ultramafic bodies in the Wuskwatim heterogeneous paragneiss, particularly at a stratigraphic level that most resembles the economically productive lower part of the Pipe Formation in the Thompson Nickel Belt (TNB), holds promise that these rocks may host Thompson-type nickel deposits. Ultramafic bodies are the source of the nickel and the sedimentary sulphides that provided the sulphur for these magmatogenic deposits (Bleeker, 1990). The wide probable extent of such rocks interleaved with the Burntwood Group in the northeastern Kisseynew Domain (KD) makes this region a major exploration frontier if the correlation with the Ospwagan Group can be confirmed. Uranium-lead zircon crystallization ages of the 'basement' orthogneiss are crucial for this task. Further detrital zircon age spectra are required for the upper exposed part of the sequence, as well as for similar gneiss at the north end of the TNB. Detrital zircon age modes from the Thompson mine and Pipe II pit do not match that of the basal quartzite at Wuskwatim Lake (Rayner et al., GS-11, this volume). Therefore, further laboratory work at the north end of the TNB is required for future exploration there and in the Wuskwatim Lake corridor. Given the complex nature of the zircons (Rayner et al., GS-11, this volume), this will require work on the sensitive high-resolution ion microprobe at the Geological Survey of Canada. The work should to be given a high priority in view of the needs of the communities of Thompson, Nelson House and Wabowden, as well as the continued economic strength of Manitoba.

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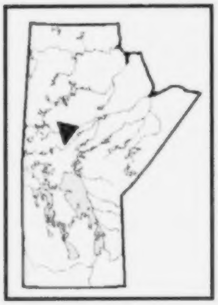
GS-10 Regional granulite-facies metamorphism in the northeastern Kisseynew Domain, Manitoba (parts of NTS 63O)

by M.L. Growdon[1], J.A. Percival[2], N. Rayner[2] and L. Murphy

Growdon, M.L., Percival, J.A., Rayner, N. and Murphy, L. 2006: Regional granulite-facies metamorphism in the northeastern Kisseynew Domain, Manitoba (parts of NTS 63O); *in* Report of Activities 2006, Manitoba Science, Technology, Energy and Mines, Manitoba Geological Survey, p. 104–115.



Summary

Observed metamorphic assemblages in the Wuskwatim Lake corridor of the northeastern Kisseynew Domain indicate upper-amphibolite- and granulite-facies conditions in Burntwood migmatite, as well as in a structurally underlying basement-cover sequence thought to be correlative with the Superior Province and Ospwagan Group in the Thompson Nickel Belt. The high-temperature metamorphism occurred at about 775°C, 6.8 kbar and 1806 to 1797 Ma.

Introduction

The Superior Boundary Zone, separating the Superior Province from the Kisseynew Domain in northern Manitoba (Figure GS-10-1), has been the focus of much recent research (Zwanzig, 1997a, b, 1999; Macek and McGregor, 1998; Macek et al., 1999, 2000; Machado et al., 1999; White et al., 2002; Zwanzig and Böhm, 2002; Zwanzig et al., 2003; Percival et al., 2004, 2005; Hulbert et al., 2005; Rayner et al., GS-11, this volume). The Kisseynew Domain to the west (Figure GS-10-1) contains structural and mineralogical evidence for a protracted tectonic and metamorphic history during the Paleoproterozoic, including terminal collision with the Superior margin around 1.83 Ga. Companion reports (Zwanzig et al., GS-9, this volume; Percival et al., GS-8, this volume) outline evidence for rocks of Superior margin affinity (i.e., the Ospwagan Group and its Archean basement) in the eastern 60 km of the Kisseynew Domain, and this report presents evidence for the upper-amphibolite- to granulite-facies metamorphism of the Burntwood and Ospwagan groups.

Tectonostratigraphic framework

Fieldwork was carried out from fly camps on Wuskwatim, Threepoint, and Tullibee lakes, as well as on selected sections of the Burntwood River (Figure GS-10-1). Mapping was mainly restricted to shoreline exposures with a few short traverses to critical field areas. The main tectonostratigraphic units in the field area are orthogneiss of probable Superior Province affinity, Ospwagan Group-like metasedimentary rocks and paragneiss of the Burntwood Group.

Rocks of probable Superior Province affinity, observed in several parts of the map area, include high-grade plutonic, migmatitic and metamorphic rocks (Percival et al., 2005). Crosscutting dikes and veins form trains of boudins that are highly attenuated and locally folded. Outcrops of orthogneiss are universally characterized by assemblages and textures indicative of high peak metamorphic temperatures and variable amounts of strain.

Rocks of the Ospwagan Group unconformably overlie Archean basement gneiss within the Thompson Nickel Belt (Zwanzig, 1997a, b; Macek et al., 1999, 2000; Zwanzig and Böhm, 2002). The age of deposition of the Ospwagan Group in the Superior Province margin was constrained to be less than 1.974 Ga, based on the youngest detrital zircon of Hamilton and Bleeker (2002), and greater than ca. 1.883 Ga, based on the age of mafic intrusions of Hulbert et al. (2005). The Ospwagan Group stratigraphy is interpreted as a succession of continental shelf sediments with overlying rift-related volcanic rocks (Zwanzig, 1997a, b; Macek et al., 1999, 2000; Zwanzig and Böhm, 2002) that experienced subsequent high-temperature, low-pressure metamorphism. The Ospwagan Group includes the basal quartzitic Manasan Formation and the calcareous Thompson Formation, above which are the siliciclastic Pipe and Setting formations. The overlying Bah Lake assemblage consists of rift-related mafic volcanic rocks (*see* Zwanzig et al., Figure GS-9-2 this volume).

In the Wuskwatim Lake area, dark purple-grey, quartz-rich, garnetiferous paragneiss with 5 to 10% leucosome was considered as possibly correlative with the Manasan Formation of the Ospwagan Group. These rocks are cut by tourmaline-bearing pegmatitic granite and aplite. Iron formation and associated biotite±garnet–bearing paragneiss were considered possibly correlative with the Pipe Formation (Figure GS-10-2; *see also* Zwanzig et al., GS-9, this volume).

The Burntwood Group of the central Kisseynew Domain is composed of migmatitic turbidites deposited around 1.85 Ga. Two detrital zircon age modes are evident: abundant 1.84 to 1.89 Ga zircons and sparse Archean grains (Machado et al., 1999; Percival et al.,

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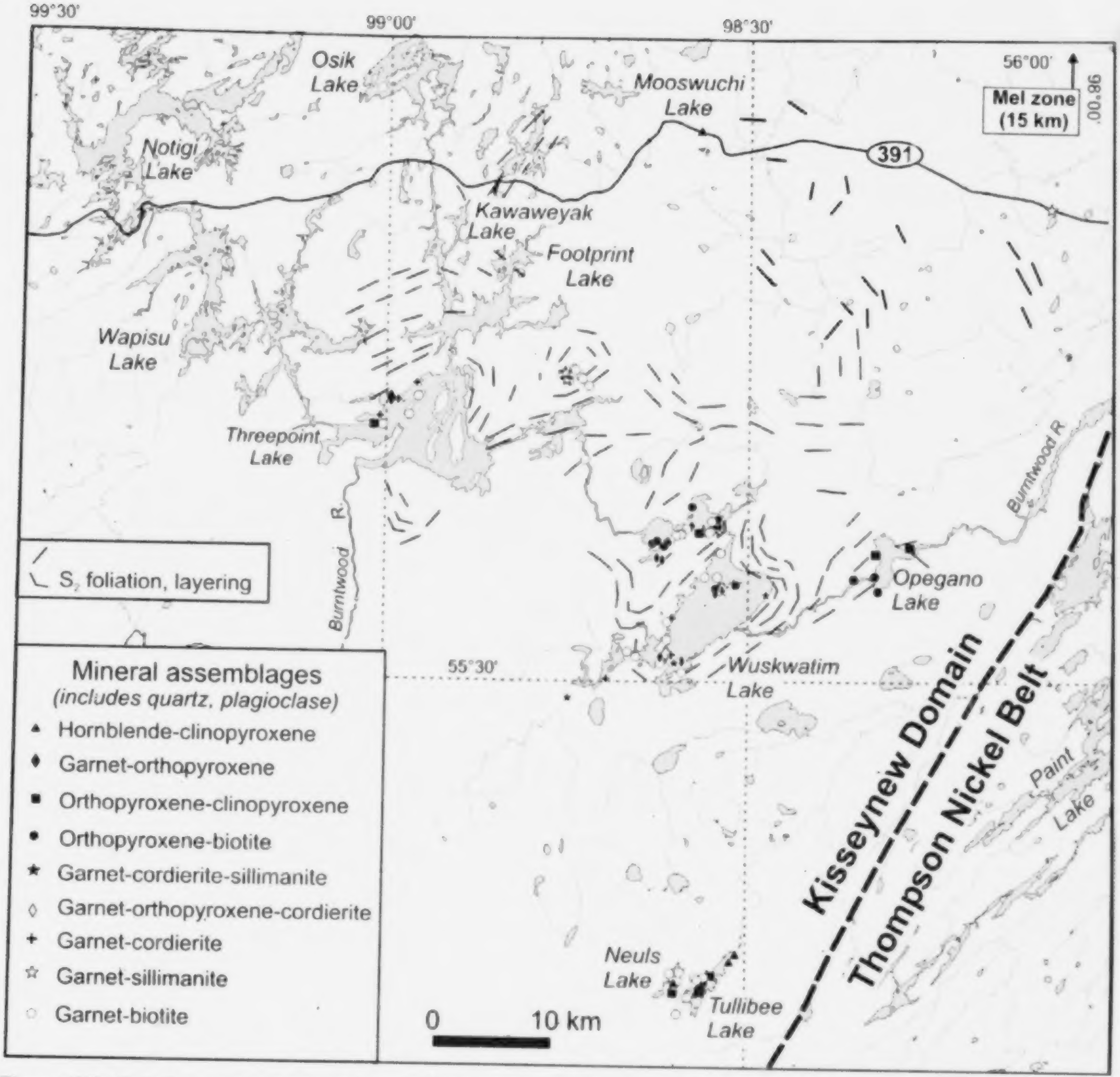
99°30'
99°00'
98°30'
56°00'
98°00'
Mel zone (15 km)
Osik Lake
Mooswuchi Lake
391
Notigi Lake
Kawaweyak Lake
Footprint Lake
Wapisu Lake
Threepoint Lake
Burntwood R.
Burntwood R.
S₂ foliation, layering
Opegano Lake
55°30'
Wuskwatim Lake
Kisseynew Domain
Thompson Nickel Belt
Paint Lake
Neuls Lake
Tullibee Lake
0
10 km
Mineral assemblages
(includes quartz, plagioclase)
▲ Hornblende-clinopyroxene
♦ Garnet-orthopyroxene
■ Orthopyroxene-clinopyroxene
● Orthopyroxene-biotite
★ Garnet-cordierite-sillimanite
◊ Garnet-orthopyroxene-cordierite
+ Garnet-cordierite
☆ Garnet-sillimanite
○ Garnet-biotite

Figure GS-10-1: *Generalized map of the northeastern Kisseynew Domain, showing the locations of features referred to in the text and observed metamorphic assemblages.*

2005). The Burntwood Group is overlain by and laterally equivalent to coarse clastic rocks of the Missi Group, which are considered to be the terrestrial extension of the turbiditic facies. The Burntwood Group is characterized in the field area by migmatitic biotite-garnet gneiss (up to 75% leucosome) with common sillimanite, cordierite and graphite (Gordon, 1989), as well as newly reported orthopyroxene (Figure GS-10-3). Rare pods of calcareous material have haloes of biotite paragneiss.

Structural geometry

The structural geometry of the field area is outlined by Percival et al. (GS-8, this volume). Four deformation fabrics have been recognized within the three tectonostratigraphic units. The D_1 deformation involved east-verging F_1 folds (Zwanzig, 1999; Zwanzig and Böhm, 2002) and the thrusting of the Burntwood Group onto the Ospwagan Group. Thrust imbrication is inferred from the sharp truncation of the Ospwagan Group by the Burntwood Group above the Pipe Formation (Zwanzig and Böhm, 2002), accompanied by an abrupt change in Nd model ages across this boundary. The main metamorphic fabrics, S_2, were produced during D_2 and D_3 deformation according to previous regional-scale studies (Zwanzig, 1990, 1997a, b, 1999; Kraus and Menard, 1997; Menard and Gordon, 1997; Zwanzig and Böhm, 2002). In the present area, these regional D_2 and D_3 events cannot be resolved and may represent a single, progressive D_2 event. The D_3 deformation resulted in the folding of S_2 into upright open

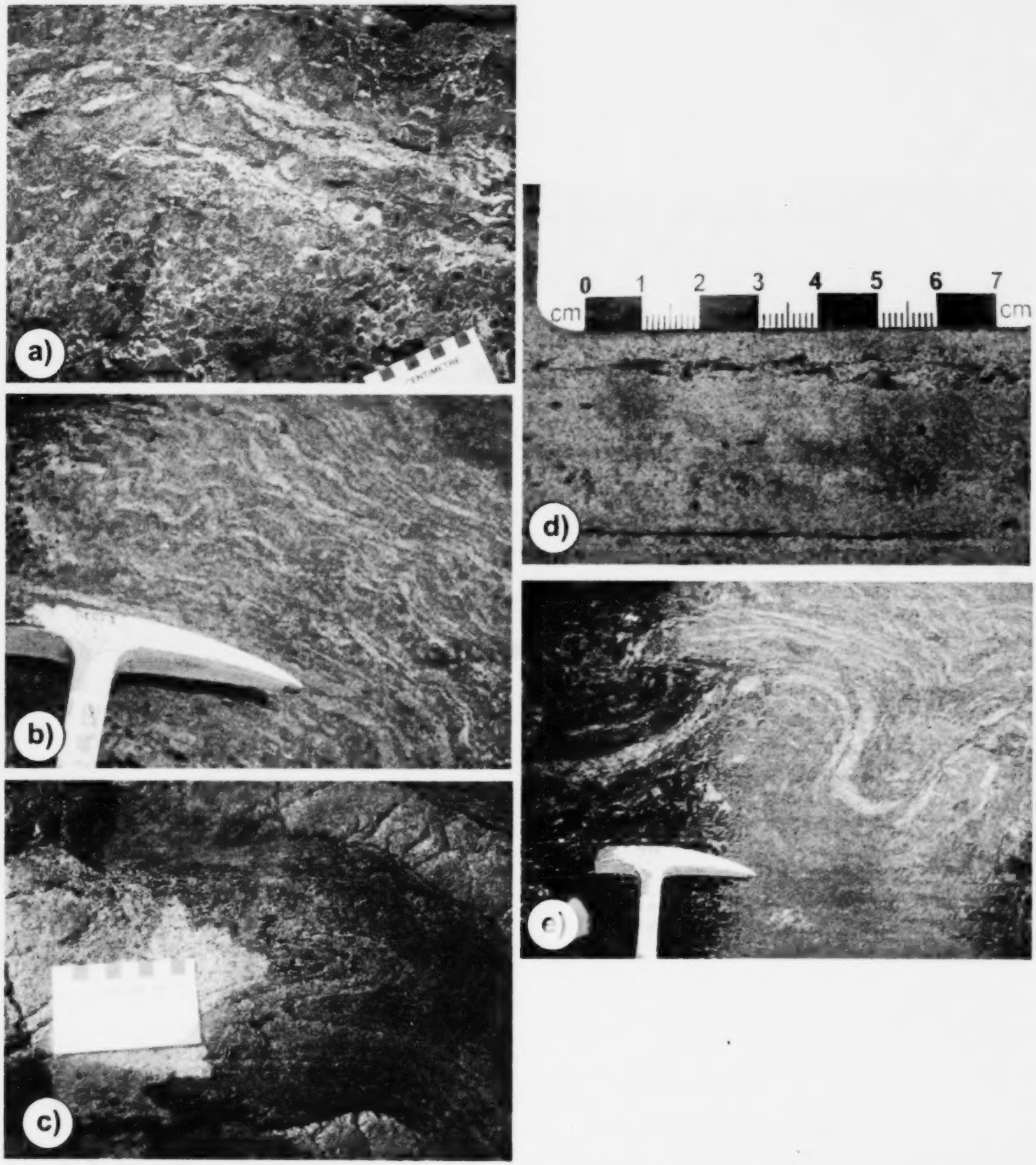

***Figure GS-10-2:** Characteristic textures and assemblages in Ospwagan-like rocks: **a)**, **b)** and **c)** show sulphide- and silicate-facies iron formation containing garnet with plagioclase reaction rims and various amplitudes of folding; **d)** and **e)** show quartz-rich units with small garnets and common folds.*

northeast-trending F_3 folds that characterize much of the field area (Zwanzig and Böhm, 2002, Figure GS-14-5). The D_3 folds are locally modified by northwest-trending F_4 crossfolds, attributed to D_4 deformation. The late crossfolds are apparent in the field as plunge reversals of F_3 fold hinges.

Structural-metamorphic relationships

Structural-metamorphic relationships within the Kisseynew Domain and the western boundary zone of the Superior Province are complex. In the eastern Kisseynew Domain, four deformation events created up to three regional foliations and five generations of folds. An early

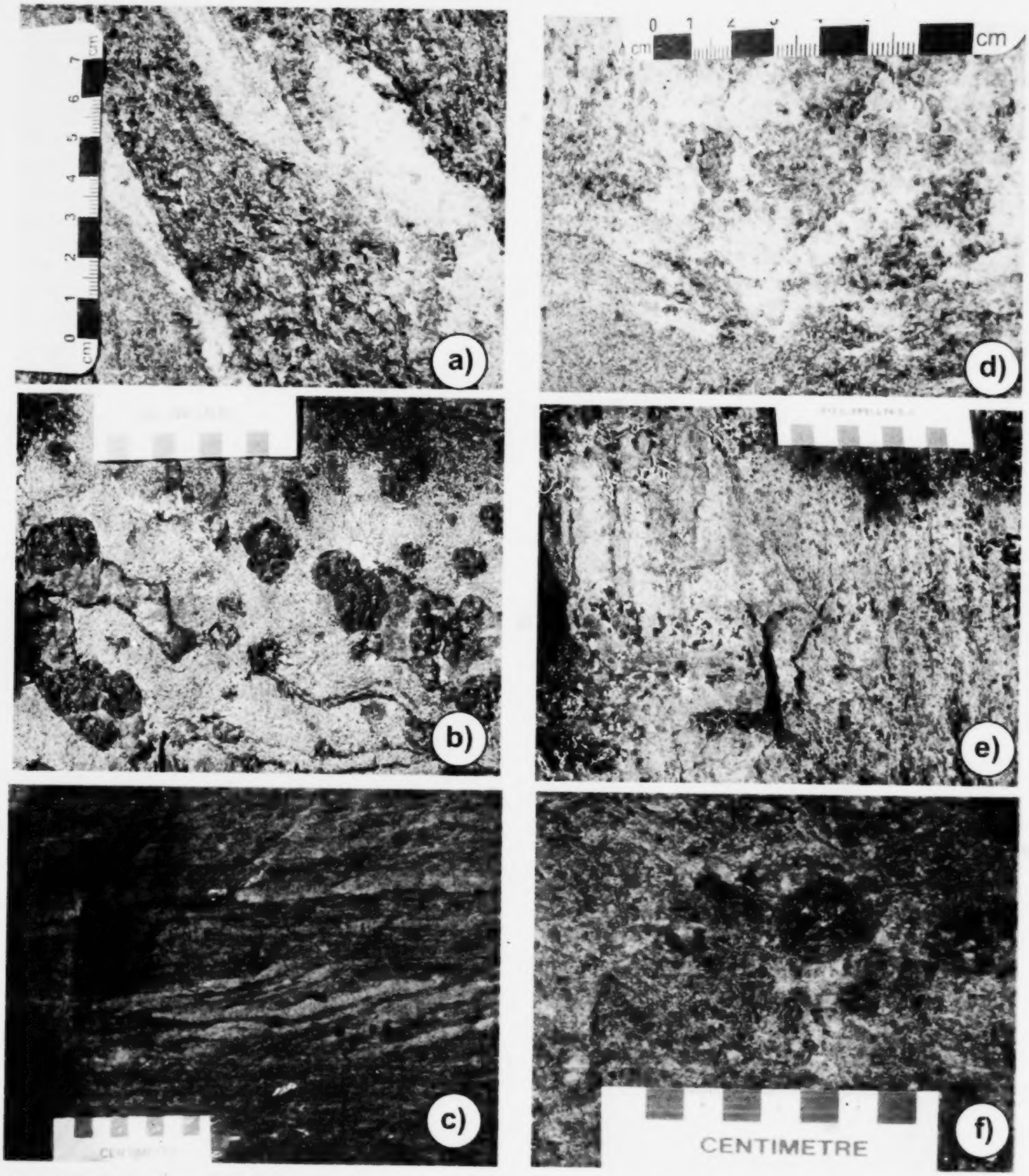

***Figure GS-10-3:** Characteristic assemblages and textures of the Burntwood Group: **a)** large garnet porphyroblasts in layers surrounded by finer quartz and biotite separated by layers of quartz, K-feldspar and cordierite; **b)** biotite schlieren surround the garnet porphyroblasts; **c)** truncated layering in migmatitic Burntwood paragneiss; **d)** biotite-garnet-quartz-plagioclase-cordierite assemblage with about 10% leucosome; **e)** the sub-granulite grade Burntwood Group has preserved sedimentary layering; **f)** large cordierite grain in leucosome in paragneiss.*

S_1 chlorite foliation formed in the Snow Lake area due to the compaction and diagenesis synchronous with, and axial planar to, F_1 folds (Menard and Gordon, 1997), although this early foliation has not been recognized in more highly metamorphosed rocks (Machado et al., 1999; Zwanzig 1999). A composite S_2-S_3 progressive foliation developed during the main metamorphism, obliterating most evidence of the earlier deformation. Garnet growth began at temperatures around 500°C and occurred prior to, during, and after the development of D_2 structures, as inferred from microtextural relationships of inclusion trails in garnets (Kraus and Menard, 1997; Menard and Gordon, 1997). A moderately annealed biotite S_2 foliation indicates that temperatures rose after the development of this foliation (Zwanzig, 1999) and likely peaked during the D_2 deformation. Gneissosity attributed to S_2 and S_3 foliations is characterized by migmatitic layering and the alignment of peak metamorphic minerals. Local mutually overprinting S_2-S_3 and F_2-F_3 relationships indicate the synchronous development of these structures. The S_2-S_3 fabrics contain kinematic indicators suggestive of extensive layer parallel flow and attenuation during D_2. Foliations attributed to S_4, defined by retrograde assemblages of muscovite-chlorite or muscovite-sillimanite, overprint S_2-S_3 fabrics. In the Wuskwatim Lake area, local S_4 is developed parallel to the axial planes of northeast-striking F_4 folds. Thus, S_4 developed after the metamorphic peak. The presence of sillimanite in some of these assemblages suggests sustained high temperatures and moderate pressures following the metamorphic peak. Northwest-trending F_4 folds, inferred from plunge reversals of F_3 axes have no observed associated fabrics. The F_4 folds are interpreted to have folded the regional metamorphic isograds, bringing granulite-facies rocks to the surface in antiformal culminations.

Metamorphism

Regional metamorphism of the northeastern Kisseynew Domain is characterized by garnet- and cordierite-bearing migmatite indicative of low-pressure, high-temperature and upper-amphibolite-facies conditions (Baldwin et al., 1979; Gordon, 1989; White, 2005). Orthopyroxene occurrences in the Wuskwatim Lake area indicate local granulite-facies conditions.

Basement mineral assemblages

Metaplutonic rocks include poorly foliated grey to pink orthogneiss with some charnockite, highly foliated tonalite containing dark green-brown orthopyroxene and inclusions of enderbite and pyroxene-bearing tonalitic orthogneiss (Figure GS-10-4). Cream-coloured leucosome with <1 cm subhedral to euhedral orthopyroxene

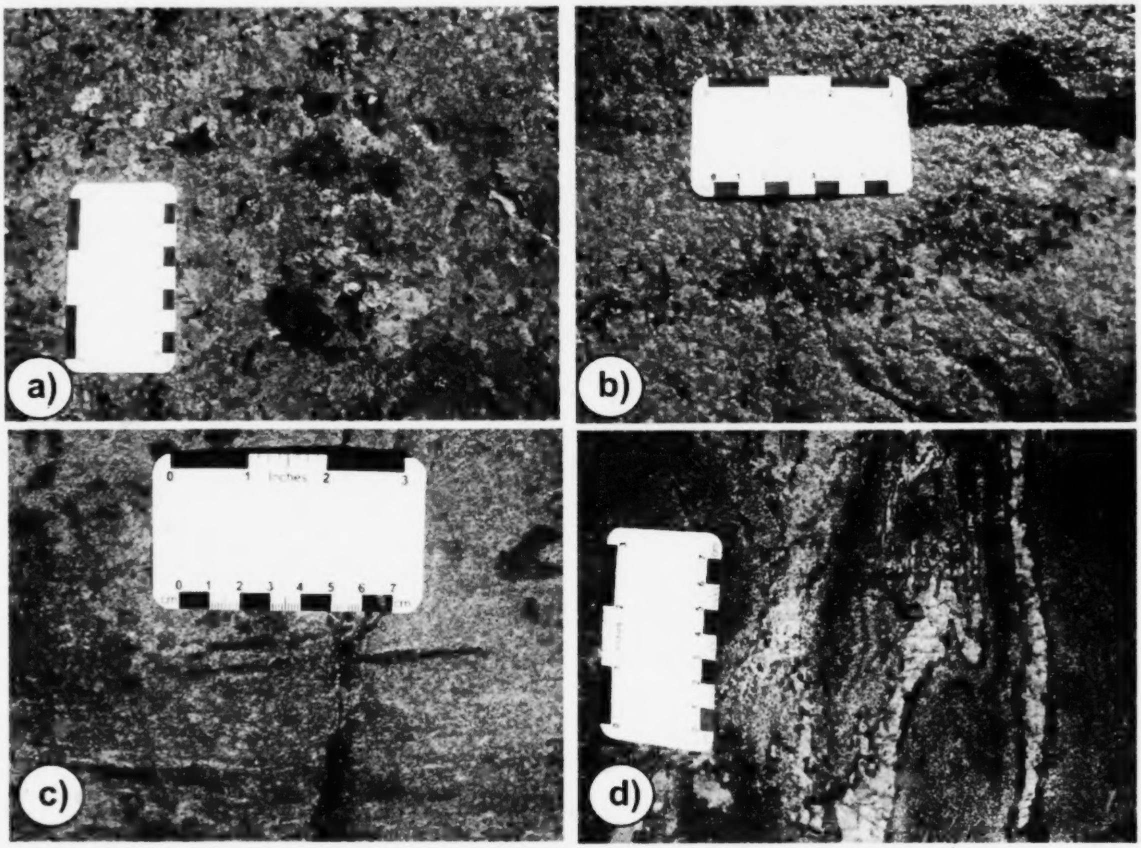

Figure GS-10-4: *Textures common in probable Archean basement in the Kisseynew Domain:* ***a)*** *small orthopyroxene and K-feldspar crystals in leucosome in charnockite;* ***b)*** *well-foliated tonalite with about 5 to 10% leucosome and melanosome rims;* ***c)*** *well-foliated pink gneiss with inclusions of tonalite;* ***d)*** *well-foliated tonalite with about 5 to 10% leucosome and melanosome rims.*

grains in a coarse-grained matrix of quartz, plagioclase and K-feldspar, constitute about 5 to 25% of these rocks. Gneissic foliation is locally tightly folded and may contain a strong rodding lineation of variable plunge. The orthogneiss is characterized by pyroxene-bearing assemblages composed of bronzy-coloured orthopyroxene, dark emerald green clinopyroxene and black hornblende in a matrix of plagioclase and quartz. Sparse paragneiss enclaves have garnet-orthopyroxene-hornblende-biotite assemblages and metabasite consists of an orthopyroxene-clinopyroxene-hornblende-plagioclase assemblage. The ubiquitous orthopyroxene in the basement assemblages indicates widespread granulite facies possibly Archean or Paleoproterozoic. More refined pressure-temperature-time estimates will be determined through electron microprobe analyses of coexisting minerals and geochronology.

Mineral assemblages in Ospwagan-like rocks

These rocks are the most mineralogically diverse group in the field. Assemblages are mainly characterized by biotite-garnet in quartzite and sulphide-bearing assemblages in iron formation. Leucosome within quartz-rich units are rich in quartz and contain orthopyroxene crystals up to 2 cm long. Local biotite-garnet-cordierite-orthopyroxene-melt assemblages indicate moderate pressures and temperatures in excess of ~750°C. This unit also contains aquamarine cordierite in association with fibrolitic sillimanite. Some retrograde replacement of cordierite by fine-grained chlorite is evident and may have been accomplished by the following hydration reaction:

Mg-cordierite + H_2O = Mg-chlorite + Al_2SiO_5 (Spear, 1995).

In the present area, the dominant aluminosilicate is coarse acicular sillimanite.

Burntwood assemblages and quantitative pressure-temperature conditions

Mineral assemblages of Burntwood paragneiss include quartz, plagioclase, biotite, garnet, sillimanite and cordierite. On a regional scale, staurolite is present at a lower metamorphic grade. Biotite and garnet are highly concentrated in the melanosome of migmatite, with minor quartz and plagioclase. Leucosome consists mostly of quartz and plagioclase and may have garnet at the margins. Small quantities of orthopyroxene are present in some localities. Its appearance may be represented by the low-pressure reaction:

biotite + plagioclase + quartz = orthopyroxene + K-feldspar + melt (Spear, 1995).

This reaction occurs at ~750 to 800°C within the sillimanite zone. The presence of cordierite in the leucosome may be represented by the reaction:

biotite + sillimanite = garnet + cordierite + melt (Spear, 1995)

and is indicative of temperatures of ~725 to 775°C (Gordon, 1989; White and Powell, 2002). These assemblages correspond to upper-amphibolite- and granulite-facies conditions, the field of which can be represented on a P-T diagram and correspond to temperatures in excess of 775°C (Figure GS-10-5).

A quantitative estimate of P-T conditions was determined for a garnet-cordierite-sillimanite-biotite-plagioclase-quartz diatexite from northeastern Wuskwatim Lake (Zwanzig et al., Figure GS-9-1, this volume). Mineral compositions were determined at the Geological Survey of Canada, Ottawa, on a Cameca Instruments SX50 electron microprobe operated in wavelength dispersive mode (Table GS-10-1). Structural formulae for core and rim compositions of weakly zoned garnet, cordierite, biotite and plagioclase grains were calculated using routine reduction procedures. Pressure-temperature conditions for core compositions were estimated from the intersection of equilibria defined by TWQ software (Berman, 1991, updated to version 2.02):

Mg-Fe cordierite = aluminosilicate + Mg-Fe garnet + quartz

anorthite = grossular + aluminosilicate + quartz

In addition, iron-magnesium exchange equilibria were calculated for garnet-cordierite and garnet-biotite pairs. The curves intersect at 6.8 kbar and 725 to 775°C (Figure GS-10-5), defining upper-amphibolite-facies conditions near the first appearance of orthopyroxene.

Metamorphic grade is slightly lower throughout most of the region (cf. Gordon, 1989), where the Burntwood paragneiss contains quartz, plagioclase, biotite, garnet and cordierite, with migmatitic leucosome and rare sillimanite. Diatexite with similar assemblages is common. Still lower-grade rocks occur locally, with relict sedimentary bedding (S_0). The primary textures are apparent in a patch north of the Burntwood River and east of Threepoint Lake (Figure GS-10-1), where assemblages are mainly garnet-biotite with some sillimanite. Retrograde reactions were only observed in the outcrop-scale mineral assemblages at one outcrop in western Threepoint Lake. There, coarse-grained platy muscovite occurs in association with sillimanite. This may indicate the coexistence of muscovite and melt, or more likely, the retrograde rehydration reaction:

sillimanite + K-feldspar + H_2O_{vapour} = muscovite + plagioclase + quartz (Spear, 1995).

Age of metamorphism

The age of peak metamorphism in the Kisseynew Domain has been most thoroughly researched by Parent et al. (1999) and Machado et al. (1999). The U-Pb ages below were determined on zircon and monazite that grew during

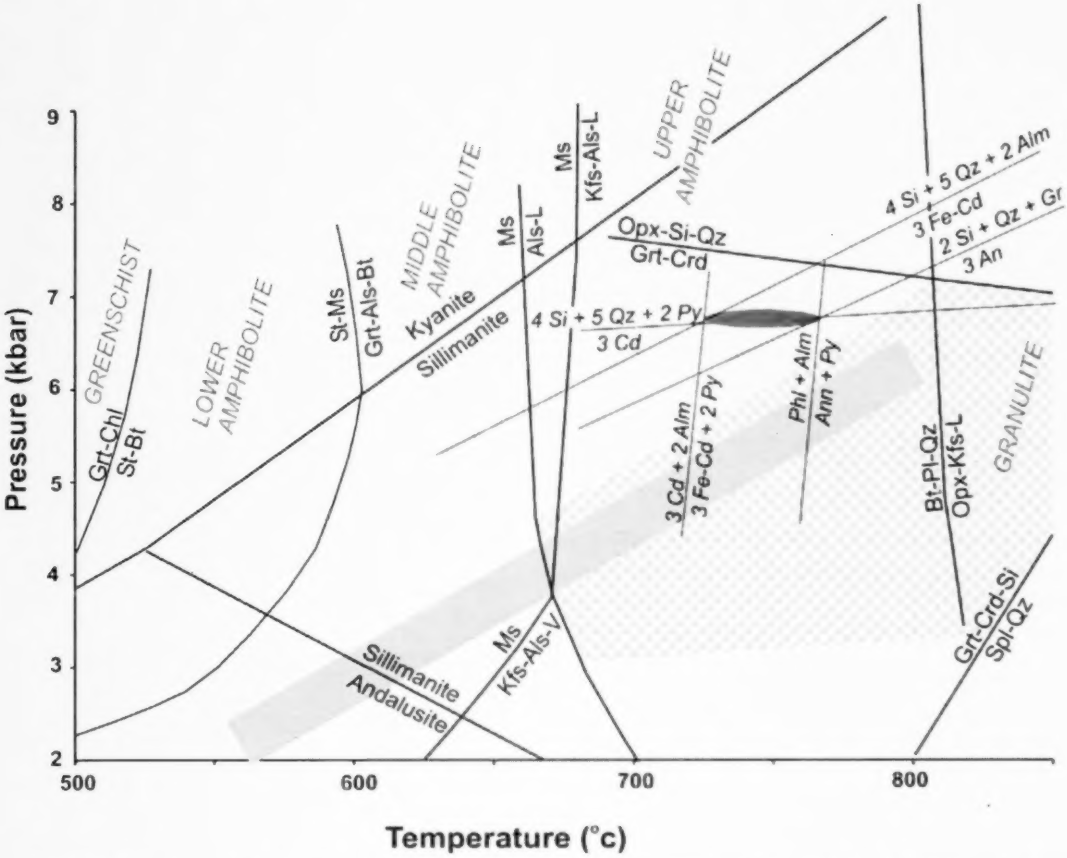

Figure GS-10-5: *Summary of metamorphic conditions and possible metamorphic equilibria in the Kisseynew Domain (pressure-temperature [P-T] grid* modified after *Percival and Skulski, 2000). The P-T estimate from this study is outlined in the medium grey oval (abbreviations: Alm, almandine; Als, aluminosilicate; An, anorthite; Ann, annite; Bt, biotite; Cd, cordierite; Chl, chlorite; Gr, grossular; Fe-Cd, iron cordierite; Kfs, K-feldspar; L, liquid; Ms, muscovite; Opx, orthopyroxene; Phl, phlogopite; Pl, plagioclase; Py, pyrope; Qz, quartz; Si, sillimanite; Spl, spinel; St, staurolite; V, vapour). The range of P-T estimates from central Kisseynew migmatite (pale grey band) is from Gordon (1989). The field of garnet-cordierite-sillimanite-melt for a metapelite with bulk FeO/MgO=1.845 from White and Powell (2002) is indicated by the stippled field. The stability field of this widespread assemblage in the central Kisseynew Domain is sensitive to pressure, temperature and bulk composition.*

Table GS-10-1: Electron microprobe data for garnet-cordierite-biotite-sillimanite-plagioclase-quartz paragneiss PBA04-08 (abbreviations: Gt, garnet; Cd, cordierite; Bt, biotite; Pl, plagioclase).

	Gt	Cd	Bt	Plg
SiO_2	37.5	47.5	35.4	62.2
TiO_2	0.1	0	5.9	0
Al_2O_3	21.2	32.5	15.5	23.4
Cr_2O_3	0	0	0.3	0
FeO	31.01	5.7	14.5	0
MnO	0.4	0	0.1	0
MgO	7.7	9.7	12.1	0
CaO	0.9	0	0	5.1
Na_2O	0	0.3	0.1	8.3
K_2O	0	0	9.3	0.5
Total	98.81	95.7	93.2	99.5

the metamorphism of the Kisseynew Domain (Machado et al., 1999; Parent et al., 1999). The oldest leucosome that records peak metamorphism contains sillimanite and is associated with F_2 folds and S_2 fabrics. Five euhedral monazites from a leucosome vein gave U-Pb ages of 1809 to 1803 Ma. Euhedral zircons within a diatexite folded by F_3 folds have an age of 1798+3/–2 Ma and constrain the minimum age of F_2 folding. The youngest pegmatite that cuts F_2 and F_3 folds, and was intruded just after deformation D_3, gives zircon U-Pb crystallization ages between 1818 and1788 Ma. The youngest of these dates was taken as the age of the pegmatite (Machado et al., 1999; Parent et al., 1999). Peak metamorphism and deformation within the Kisseynew Domain was interpreted to be continuous over the 30 Ma period of 1818 to 1785 Ma (Parent et al., 1999). Machado et al. (1999) suggested that high-grade metamorphic conditions persisted in the Kisseynew Domain until at least 1775 Ma. Somewhat younger peak metamorphism is indicated for the Superior Boundary Zone and Thompson Nickel Belt. Metamorphic zircon and monazite from the Thompson area yield U-Pb ages around 1770 Ma (Rayner et al., GS-11, this volume) and pegmatite has comparable crystallization ages (Machado et al., 1999).

This paper reports new monazite crystallization ages from a rock in the Wuskwatim Lake area to provide additional constraints on the timing of peak metamorphism. The sample is a felsic sedimentary unit initially described by Percival et al. (2005) and associated with the Ospwagan group sediments based on a small detrital zircon dataset (Geological Survey of Canada [GSC] lab number 8334). Additional detrital results for this sample are given in Zwanzig et al. (GS-9, this volume) and indicate a solely Archean source for the sediment, broadly consistent with Ospwagan-like Superior margin sedimentation.

Monazite ages determined by isotope dilution thermal ionization mass spectrometry (ID-TIMS) at the Geochronology Laboratory, Geological Survey of Canada, follow the sample dissolution and chemical methods as described in Parrish et al. (1987) and Davis et al. (1998). Individual grains were spiked with a mixed ^{205}Pb-^{233}U-^{235}U tracer solution calibrated to ±0.1% against a gravimetric solution and dissolved in high-pressure bombs in 6 N HCl. Data reduction and error propagation follow methods outlined in Roddick (1987). Uranium and lead isotopic ratios were measured using a Thermo Triton™ mass spectrometer operated in static multicollection mode. The ^{205}Pb, ^{206}Pb, ^{207}Pb and ^{208}Pb isotopes were measured simultaneously in Faraday collectors, with ^{204}Pb in an axial ion-counting secondary electron-multiplier. A Pb mass fractionation correction of 0.10 ±0.04%/amu was applied as determined by replicate analyses of the NBS981 standard (Table GS-10-2). Uranium fractionation was corrected using the ^{233}U-^{235}U double spike and was typically in the range of 0.12%/amu. Corrections for common Pb were made using Stacey-Kramers (1975) compositions. Concordia diagrams were generated using Isoplot™, version 3.00 (Ludwig, 2003). All ages and ellipses are given at the 2σ error level. The results are presented in Table GS-10-2 and plotted on Figure GS-10-6.

Seven monazite grains covering a range of size, colour, quality and morphology were selected for single-grain analysis. The ^{207}Pb-^{206}Pb ages range from 1797 to 1806 Ma but are consistently reversely discordant by 0.3 to 0.5%, with the exception of one concordant result. The reverse discordance is likely an analytical artifact, perhaps related to the dissolution of the monazites. The reverse discordance suggests that the U-Pb ages are inaccurate and therefore only the Pb-Pb ages will be considered further. The ^{207}Pb-^{206}Pb ages do not form a single statistical population, suggesting some geological scatter. This is consistent with prolonged metamorphism as proposed by previous workers (Gordon, 1989; Machado et al., 1999; Parent et al., 1999), although we cannot determine whether this was the result of two or more punctuated episodes or continuous growth over at least the 1806 to 1797 Ma interval. Backscattered electron imaging of the internal structure of the monazites along with in situ analysis would be needed to constrain this.

Summary and discussion

Deformation and high-grade metamorphism in the Kisseynew Domain occurred over a period of ~30 Ma (1818–1785 Ma) and created the dominant regional gneissosity and migmatitic layering. Deformation in the Kisseynew Domain is the product of collisions between volcanic arcs of the Trans-Hudson Orogen and subsequent collision with the Superior Province (Zwanzig, 1990; Ansdell, 2006). The D_1 deformation occurred pre-peak metamorphism and resulted in thrusting of the Burntwood Group onto the Ospwagan Group along a basal thrust fault (Zwanzig and Böhm, 2002). It is unclear whether S_1 in the Snow Lake Belt to the southwest is related (Menard and Gordon, 1997; Machado et al., 1999; Zwanzig, 1999). Regionally, D_2 deformation and peak metamorphism, indicated by metamorphic assemblages present in S_2-S_3 fabrics and foliation-parallel leucosome, occurred at temperatures of 750 to 800°C and pressures less than 5 kbar (Gordon, 1989; Zwanzig, 1990; Menard and Gordon 1997; White, 2005). In the Wuskwatim Lake region, post-peak metamorphic upright F_4 folds overprint the S_2-S_3 composite fabric. Together with younger crossfolds, these structures produce regional structural culminations that expose the basement-cover sequence and granulite-facies metamorphic rocks that equilibrated at pressures approximately 2 kbar higher (equivalent to 6 km depth) than the regional erosion level.

The single temperature estimate available for the Wuskwatim Lake area (Figure GS-10-1 and -5) falls within the range of regional peak metamorphic temperatures

Table GS-10-2: U-Pb analytical data for monazite, lab number Z8334.

Fract.	Wt. ug	U ppm	Pb[1] ppm	$\frac{^{206}Pb}{^{204}Pb}$[2]	Pb[3] pg	Isotopic Ratios[4]								Ages (Ma)[6]						Disc (%)
						$\frac{^{208}Pb}{^{206}Pb}$	$\frac{^{207}Pb}{^{235}U}$	±1SE Abs	$\frac{^{206}Pb}{^{238}U}$	±1SE Abs	Corr.[5] coeff.	$\frac{^{207}Pb}{^{206}Pb}$	±1SE Abs	$\frac{^{206}Pb}{^{238}U}$	±2SE	$\frac{^{207}Pb}{^{235}U}$	±2SE	$\frac{^{207}Pb}{^{206}Pb}$	±2SE	
M1	5	3503	43027	13005	27	42.88	4.88258	0.00556	0.32196	0.00029	0.9251	0.10999	0.00005	1799.3	2.8	1799.3	1.9	1799.2	1.7	-0.01
M2	5	1245	17551	8234	15	49.20	4.89258	0.00567	0.32303	0.00029	0.9404	0.10985	0.00005	1804.5	2.8	1801	2.0	1796.9	1.6	-0.49
M3	5	2476	25795	8483	29	36.00	4.91523	0.00595	0.32372	0.00031	0.9237	0.11012	0.00005	1807.9	3.0	1804.9	2.0	1801.4	1.8	-0.41
M4	5	1603	14585	13539	12	31.27	4.92451	0.00621	0.32404	0.00034	0.9412	0.11022	0.00005	1809.4	3.3	1806.5	2.1	1803.1	1.6	-0.4
M5	1	2582	13546	4976	11	17.55	4.93797	0.00614	0.3243	0.00032	0.9109	0.11043	0.00006	1810.7	3.2	1808.8	2.1	1806.5	1.9	-0.27
M6	1	1480	12209	8155	4	28.24	4.92908	0.00576	0.32415	0.00033	0.8374	0.11029	0.00007	1810.0	3.2	1807.2	2.0	1804.1	2.3	-0.37
M7	1	2198	14293	9886	4	22.06	4.91671	0.00593	0.32373	0.00033	0.8771	0.11015	0.00006	1807.9	3.3	1805.1	2.0	1801.9	2.1	-0.39

Notes:

[1] Radiogenic Pb

[2] Measured ratio, corrected for spike and fractionation

[3] Total common Pb in analysis corrected for fractionation and spike

[4] Corrected for blank Pb and U and common Pb, errors quoted are 1 σ absolute; procedural blank values for this study are 0.1 pg U and 1 pg Pb
Pb blank isotopic composition is based on the analysis of procedural blanks; corrections for common Pb were made using Stacey-Kramers compositions.

[5] Correlation Coefficient

[6] Corrected for blank and common Pb, errors quoted are 2 σ in Ma
The error on the calibration of the GSC Pb-U-Th spike utilized in this study is 0.22% (2σ).

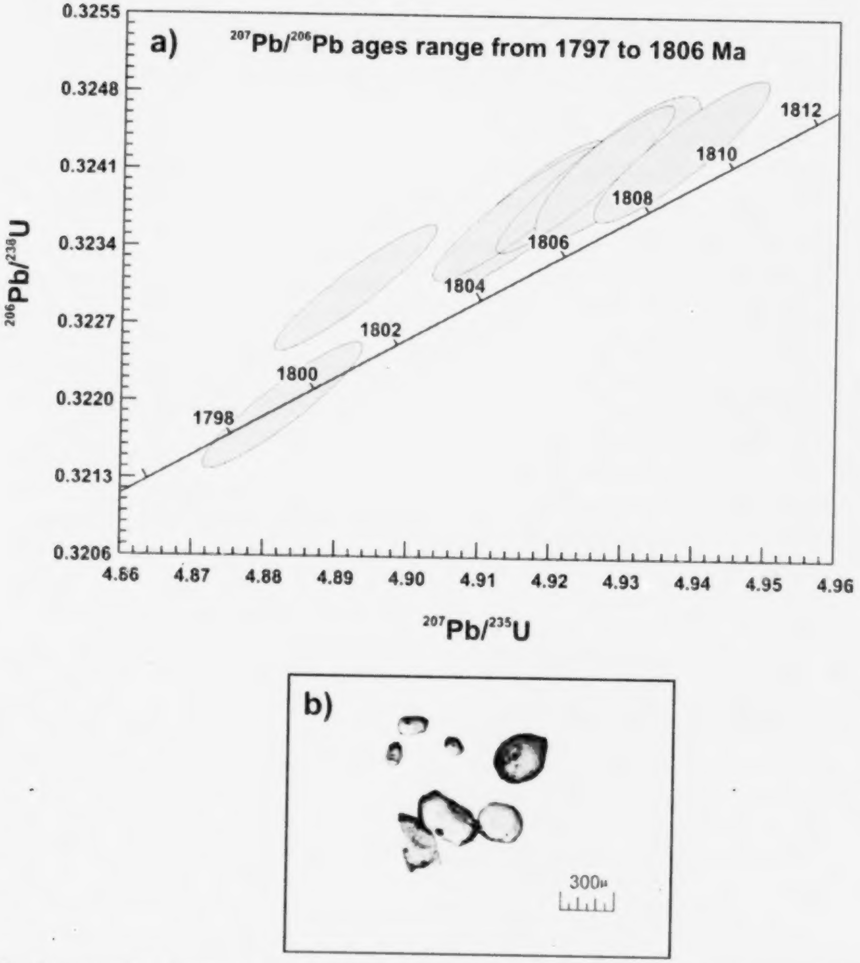

***Figure GS-10-6:** a) Concordia diagram of U-Pb showing the age of monazites from an Ospwagan-like quartz-rich metasedimentary rock. Ages between 1797 and 1806 Ma are interpreted to record the time of peak metamorphic conditions; b) shows the analyzed grains.*

at 5.5 kbar (Gordon, 1989; Menard and Gordon, 1997). It is possible that the geothermometers re-equilibrated during cooling, but further analyses are required to test this hypothesis. Alternatively, migmatite temperatures may have been buffered by melting reactions such that higher temperatures could only be achieved through a loss of granitic melt (cf. White and Powell, 2002). Similar temperatures could have therefore prevailed within a considerable depth range. If the hypothesis of constant temperature at pressures of 5 to 7 kbar within the central Kisseynew Domain is valid, it presents an interesting contrast with the southern flank of the metamorphic culmination. There, Kraus and Menard (1997) inferred that the temperature gradient occurred at constant pressures between 4 and 6 kbar.

Metamorphic assemblages within the Kisseynew Domain are not strongly retrogressed. Mineral assemblages record near-peak or peak metamorphic conditions with few apparent outcrop-scale retrograde reactions. The slow cooling during uplift and exhumation of these rocks to shallow depths was either incubated by the heat from late magmatism, or occurred in the absence of free water, restricting rehydration reactions and regional retrogression. The lack of retrograde overprinting makes the determination of the peak metamorphic conditions relatively straightforward, but presents a challenge to defining the post-peak metamorphic evolution.

Economic considerations

Granulite-facies metamorphic rocks generally have limited economic potential; however, this study illustrates that high metamorphic grade serves as a first-order guide to exhumed deep crustal sections in the northeastern Kisseynew Domain, which may include sub-Burntwood strata. If correlations are validated between the high-grade Ospwagan-like rocks in the Wuskwatim Lake area and the Ospwagan type section in the Thompson Nickel

Belt, other granulite-facies areas could host similar units. Given the generally recessively weathering nature of the Ospwagan Group, occurrences of metamorphic orthopyroxene provide a broader target for exploration in this environment.

Conclusions

Metamorphic mineral assemblages in the Burntwood Group and in the meta-argillaceous sections of the Ospwagan Group are nearly identical, indicating common peak conditions in the upper-amphibolite and granulite facies, at temperatures around 775°C and pressures near 7 kbar. The basement, as well as the Ospwagan and Burntwood groups, may have had distinct metamorphic histories. Retrograde assemblages within the Kisseynew Domain are sparse. Future petrographic analyses and isotopic dating will help constrain the metamorphic pressure-temperature-time path of the diverse tectonostratigraphic sequences in the northeastern Kisseynew Domain.

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GS-11 Detrital zircon provenance of the Pipe Formation, Ospwagan Group, Thompson Nickel Belt, Manitoba, NTS 63O8

by N. Rayner[1], H.V. Zwanzig and J.A. Percival[1]

Rayner, N., Zwanzig, H.V. and Percival, J.A. 2006: Detrital zircon provenance of the Pipe Formation, Ospwagan Group, Thompson Nickel Belt, Manitoba, NTS 63O8; *in* Report of Activities 2006, Manitoba Science, Technology, Energy and Mines, Manitoba Geological Survey, p. 116–124.

Summary

Two samples of the Pipe Formation in the Thompson Nickel Belt were processed for U-Pb sensitive high-resolution ion microprobe (SHRIMP) ages of detrital zircons in an attempt to further constrain the age of deposition of the Ospwagan Group, which hosts the nickel deposits. A pelite from the Thompson mine and semipelite from the Pipe II pit both yielded a population of only Neoarchean grains with the primary age mode of ca. 2.7 Ga, similar to previous work on the entire Ospwagan Group sediment section. No Proterozoic grains were found to confirm the maximum age of deposition of <1974 Ma suggested by a single zircon grain in a previous study. The robust nature of the age distribution, however, suggests that detrital zircon modes are useful in distinguishing the Ospwagan Group from superficially similar rocks that may belong to a different sequence and are unlikely to contain nickel deposits.

Introduction

World-class nickel deposits make the Thompson Nickel Belt (TNB) an economically vital segment of the Superior Boundary Zone, where it adjoins the Trans-Hudson Orogen in Manitoba. The deposits occur in the highly metamorphosed and deformed Ospwagan Group sedimentary cover, which was folded with the remobilized Archean basement that extends into the Superior craton to the southeast. Most deposits are hosted in the Pipe Formation, a metapelite and iron formation unit in the central part of the Ospwagan Group. They are always associated and commonly in contact with ultramafic bodies that are interpreted to have been the source of the nickel for the deposits. Parts of the Pipe Formation are highly sulphidic and provided the sulphur for these magmatogenic deposits (Bleeker, 1990).

Despite considerable previous work, the age of the lower Ospwagan Group is poorly constrained between the youngest detrital zircon at ca. 2530 Ma (Hamilton and Bleeker, 2002) and intrusions crystallized at ca. 1.89 Ga (Zwanzig et al., 2003; Percival et al., 2004). A single grain of Paleoproterozoic zircon dated at ca. 1974 Ma was recovered from the upper part of the sequence by Hamilton and Bleeker (2002) along with a population of otherwise Neoarchean detrital grains with the primary age mode of ca. 2.7 Ga, but this Paleoproterozoic age needs confirmation. Other dating attempts also recovered large populations of only Archean zircons (N. Machado, pers comm, 2000; Zwanzig et al., 2001). The cited U-Pb geochronology and Nd isotope work of Zwanzig and Böhm (2002) show that the provenance of the sediments was the Archean Superior craton to the southeast of the TNB.

To this end, detrital zircon provenance profiles have been determined using the sensitive high-resolution ion microprobe (SHRIMP) for two new samples of the Pipe Formation. The majority of the data were collected in reconnaissance mode (six isotopes per four scans). This allowed analysis of a greater number of grains in a search for Paleoproterozoic detrital zircon. Ages of metamorphic overgrowths on the detrital zircons were also determined by SHRIMP and are consistent with high-grade metamorphism at ca. 1.78 Ga as reported by other workers (e.g., Bleeker, 1990a; Hamilton and Bleeker, 2002). New monazite ages determined by thermal ionization mass spectrometry (TIMS) are slightly younger.

A crystallization age of 1880 ±5 Ma for the ultramafic rocks, and therefore of the mineralization, was previously determined from zircon in a pyroxenite (Hulbert et al., 2005). Despite a similar approximate Re-Os age from sulphide ores (Hulbert et al., 2005), this has not been fully accepted by all geologists working in the TNB. To eliminate this disagreement, one of the new samples from the Pipe Formation was taken at the contact with a mineralized ultramafic body in hopes of finding zircon overgrowth formed during contact metamorphism on the detrital grains.

Geological background

The TNB forms the southeastern external zone of the Trans-Hudson Orogen in Manitoba (Figure GS-11-1). It comprises a basement of polydeformed Archean orthogneiss and migmatite, tightly folded with the Ospwagan Group cover sequence that is believed to have been deposited during the Paleoproterozoic on an outer shelf and upper slope environment (Zwanzig et al., work in progress, 2006). The Superior Boundary Zone along the TNB is tectonically unique in having experienced

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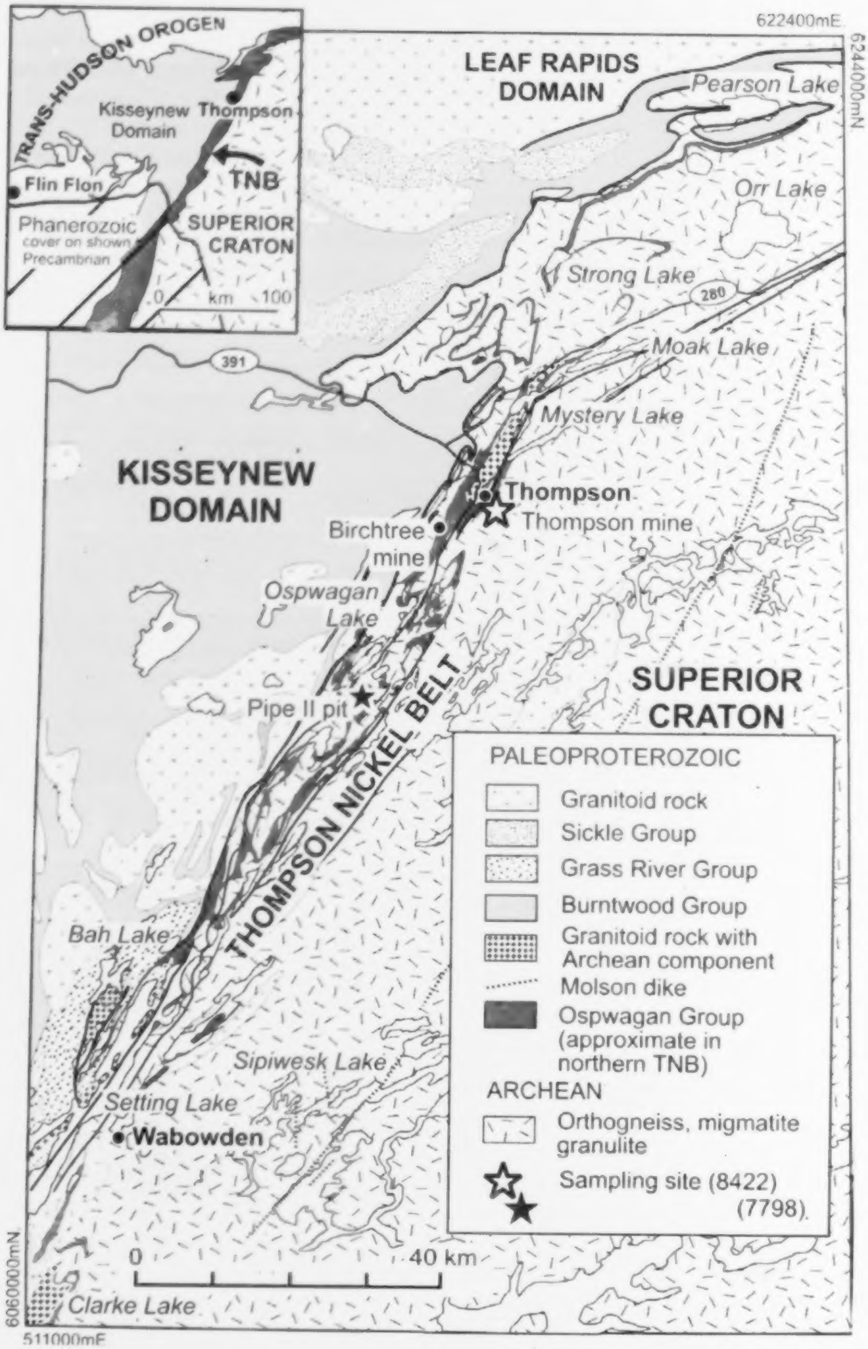
622400mE
6244000mN
TRANS-HUDSON OROGEN
Kisseynew Domain
Thompson
TNB
Flin Flon
Phanerozoic cover on shown Precambrian
SUPERIOR CRATON
0 km 100
LEAF RAPIDS DOMAIN
Pearson Lake
Orr Lake
Strong Lake
280
391
Moak Lake
Mystery Lake
KISSEYNEW DOMAIN
Thompson
Thompson mine
Birchtree mine
Ospwagan Lake
Pipe II pit
THOMPSON NICKEL BELT
SUPERIOR CRATON
PALEOPROTEROZOIC
Granitoid rock
Sickle Group
Grass River Group
Burntwood Group
Granitoid rock with Archean component
Molson dike
Ospwagan Group (approximate in northern TNB)
ARCHEAN
Orthogneiss, migmatite granulite
Sampling site (8422) (7798)
Bah Lake
Sipiwesk Lake
Setting Lake
Wabowden
0 40 km
Clarke Lake
6060000mN
511000mE

Figure GS-11-1: *Simplified geological map of the Thompson Nickel Belt showing the locations of detrital zircon samples.*

1890 to ca. 1880 Ma felsic calcalkaline plutonism and deformation, interpreted to have taken place in a continental arc setting (Percival et al., 2004, 2005). The 1883 Ma Molson mafic dike swarm (Heaman et al., 1986) was intruded within, and southeast of, the TNB. A fringing, coarse siliciclastic overlap succession between the TNB and the internal zone of Trans-Hudson Orogen (Grass River Group of Zwanzig, 1997) is estimated to have been deposited between 1.85 and 1.83 Ga, similar to its correlatives (the Missi and Sickle groups). This is interpreted to mark the onset of collision with the Superior craton (White et al., 2002; Zwanzig and White, 2002) and the structural juxtaposition with the Burntwood Group that underlies much of the Kisseynew Domain in the internal zone. The intrusion of stitching alkaline to sanukitoid plutons at 1835 Ma supports the proposed age of collision (Zwanzig et al., 2003). Intense syn- to postcollisional deformation involved thrusting from the internal zone followed by the formation of fold nappes (Bleeker, 1990a, b; Zwanzig and Böhm, 2002) and granite to syenite intrusion. Tight upright folds formed during later metamorphism and intracontinental transpression lasting to 1770 Ma and younger (Bleeker, 1990a, b). Metamorphic grade ranges from middle amphibolite to biotite-granulite facies. The thermotectonism has so modified the TNB that no single rigorous model for its age and origin exists.

Despite these problems, the Ospwagan Group is known to lie unconformably on the Superior Province basement. A regional compilation (Thompson Nickel Belt Geology Working Group, 2001a, b, c, d) confirms the original subdivision of the group into five conformable formations (Bleeker, 1990b; Bleeker and Macek, 1998) that can be recognized along at least 200 km of strike length. Although strongly deformed and attenuated, the sequence is generally coherent and can be crossed from the basal unconformity into the synclinal core of the large regional folds (Bleeker, 1990a, b; Zwanzig, 1998). The sequence consists of clastic and chemical sedimentary rocks capped by mafic volcanic rocks. Detailed sections of Ospwagan Group rocks were established on clean exposures on the shoulders of the Pipe II pit and Thompson pits (Figure GS-11-2), and from lakeshore exposures (Bleeker and Macek, 1988; Bleeker, 1990b; Zwanzig, 1997, 1999). From these separate exposures, an almost complete lithostratigraphic succession has been reconstructed as summarized in Figure GS-11-2.

Sample details

Detrital zircons were recovered from two Ospwagan Group samples. The first is a Pipe Formation semipelite (PBA03-35, Geological Survey of Canada [GSC] lab number 7798), collected from the shoulder of the Pipe II pit. The 6 cm wide sample was sawn out of a section through approximately 10 semipelite beds (Figure GS-11-3). Zircons recovered from sample 7798 vary from large euhedral prisms to well-rounded ovoid grains to small euhedral to subhedral prisms. All morphologies exhibit moderate to strong oscillatory zoning and most have very thin (<5 µm), high U rims. The rims are too narrow to be dated by the ion probe but based on their appearance and ubiquity they likely represent Hudsonian metamorphic growth.

The second sample is a pelite, also from the Pipe Formation, in contact with a mineralized ultramafic intrusive body (provided by Inco Limited, sample number 768262, GSC lab number 8422). The sample is from the hangingwall side of an ultramafic unit in the north end of the Thompson mine, 2500 ft. level. This sample was initially collected in an attempt to indirectly determine the age of ultramafic magmatism by dating U-bearing metamorphic minerals that were thought to have formed during contact metamorphism. While the authors did not succeed in constraining the age of contact metamorphism, the results from this sample provide constraints on the detrital population and Trans-Hudson metamorphism. Zircons recovered from sample 8422 are mainly prismatic

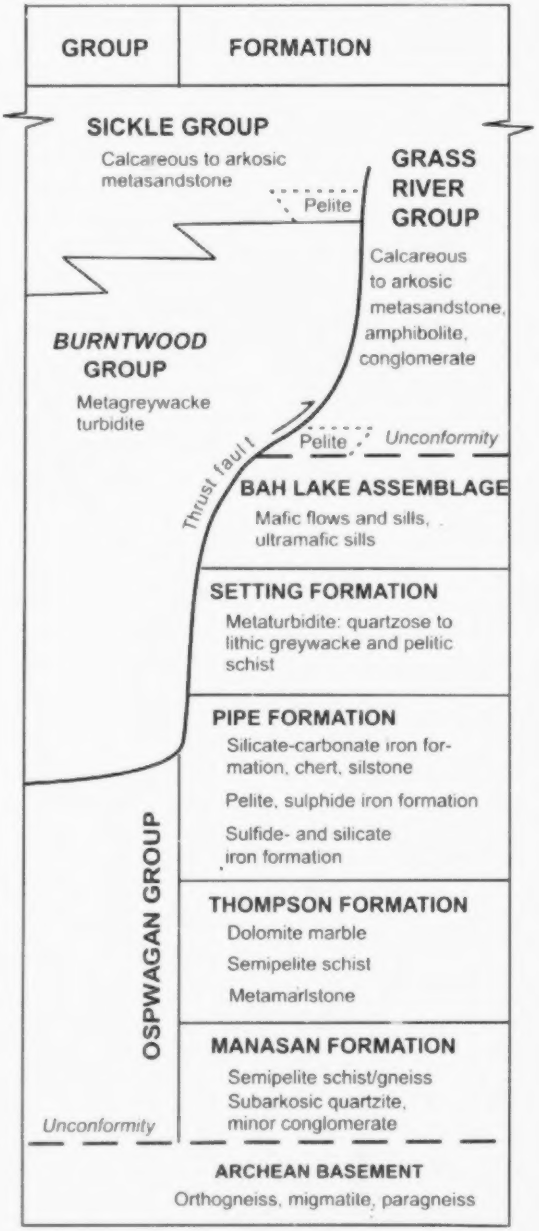
GROUP
FORMATION
SICKLE GROUP
Calcareous to arkosic metasandstone
Pelite
GRASS RIVER GROUP
Calcareous to arkosic metasandstone, amphibolite, conglomerate
BURNTWOOD GROUP
Metagreywacke turbidite
Thrust fault
Pelite
Unconformity
BAH LAKE ASSEMBLAGE
Mafic flows and sills, ultramafic sills
SETTING FORMATION
Metaturbidite: quartzose to lithic greywacke and pelitic schist
PIPE FORMATION
Silicate-carbonate iron formation, chert, silstone
Pelite, sulphide iron formation
Sulfide- and silicate iron formation
OSPWAGAN GROUP
THOMPSON FORMATION
Dolomite marble
Semipelite schist
Metamarlstone
MANASAN FORMATION
Semipelite schist/gneiss
Subarkosic quartzite, minor conglomerate
Unconformity
ARCHEAN BASEMENT
Orthogneiss, migmatite, paragneiss

Figure GS-11-2: *Succession of supracrustal rocks in the Thompson Nickel Belt and adjacent part of the Kisseynew Domain.*

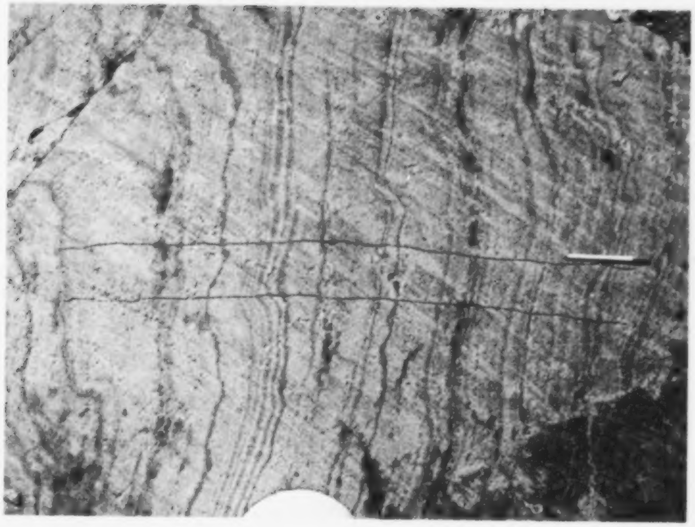

***Figure GS-11-3:** Photograph of sample site at Pipe II pit showing Pipe Formation semipelite with planned cutting lines indicated (16 cm pen for scale).*

with oscillatory-zoned, high U overgrowths and low U, unzoned cores. The monazite is pale yellow and platy with few inclusions or fractures. Biotite and other minerals that were adhered to the margins of the monazite were removed with brief air abrasion.

Analytical methods

Procedures followed for SHRIMP zircon U-Pb analysis are those described by Stern (1997), with standards and U-Pb calibration methods from Stern and Amelin (2003). The internal features of the zircons (such as zoning, structures, alteration, etc.) were characterized with backscattered electrons (BSE) utilizing a Cambridge Instruments scanning electron microscope (Figure GS-11-4). Analyses were conducted using an $^{16}O^-$ primary beam. Details on the spot size, the primary beam intensity, the species, the number of scans and the U-Pb calibration error can be found in the footnotes of tables 1 and 2 in DRI2006004[2]. Off-line data processing was accomplished using customized in-house software. Isoplot v. 2.49 (Ludwig, 2003) was used to generate concordia plots and calculate weighted means. All ages in the text and the ellipses plotted in the figures have errors reported at the 2σ uncertainty level.

Monazite ages determined by isotope dilution thermal ionization mass spectrometry (ID-TIMS) at the Geochronology Laboratory, Geological Survey of Canada follow the sample dissolution and chemical methods as described in Parrish et al. (1987) and Davis et al. (1998). Individual grains were spiked with a mixed ^{205}Pb-^{233}U-^{235}U tracer solution calibrated to ±0.1% against a gravimetric solution and dissolved in high-pressure bombs in 6 N HCl. Data reduction and error propagation follow methods outlined in Roddick (1987). Uranium and lead isotopic ratios were measured using a Thermo Triton™ mass spectrometer operated in static multicollection mode. The ^{205}Pb, ^{206}Pb, ^{207}Pb, and ^{208}Pb isotopes were measured simultaneously in Faraday collectors, with ^{204}Pb in an axial ion counting secondary electron multiplier. A Pb mass fractionation correction of 0.10 ±0.04%/amu was applied as determined by replicate analyses of the NBS981 standard. Uranium fractionation was corrected using the ^{233}U-^{235}U double spike and was typically in the range of 0.12%/amu.

Results

The primary goal of studying sample 7798 was to try to confirm the presence of Paleoproterozoic material in the Ospwagan Group as suggested by the single zircon identified by Hamilton and Bleeker (2002), rather than to precisely constrain the age and composition of the Archean zircons. For this reason, only a small number of grains (n=13) were analyzed using the typical ten isotopes per five scans routine of SHRIMP dating. The majority of the data (n=80) were collected in reconnaissance mode (six isotopes per four scans). This allowed analysis of a greater number of grains, but the dataset is of lower precision and does not include Th compositional data.

The combined SHRIMP results (typical and reconnaissance modes) for sample 7798 are presented in DRI2006004, Table 1 and plotted in Figure GS-11-5. All data are included in the concordia diagram; however, 12 of the analyses are excluded from the cumulative probability curve as they are greater than 5% discordant. The ^{207}Pb/^{206}Pb age of discordant zircons cannot be relied upon to provide an accurate representation of the age of the detritus; discordant results can only be considered as minimum ages. Concordant ages range from 2595 to 2934 Ma and have a dominant mode at ca. 2700 Ma. Of the 82 concordant zircons, only four give ages in excess of 2825 Ma. The data clearly show that no Proterozoic grains were present in the sample population and that the primary age mode is the same as for the previous work (Hamilton and Bleeker, 2002).

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[2] MGS Data Repository Item DRI2006004, containing the sensitive high-resolution microprobe (SHRIMP) U-Pb detrital results for sample 7798, Pipe Formation, Pipe II pit, and the SHRIMP and thermal ionization mass spectrometry (TIMS) data for sample 8422, Pipe Formation, Thompson mine, 2500 ft. level used to compile this report, is available on-line to download free of charge at www2.gov.mb.ca/itm-cat/freedownloads.htm, or on request from minesinfo@gov.mb.ca or Mineral Resources Library, Manitoba Science, Technology, Energy and Mines, 360–1395 Ellice Avenue, Winnipeg, MB R3G 3P2, Canada.

The original aim for sample 8422 was to determine the timing of contact metamorphism. Evaluating the detrital population was not a high-priority objective and therefore detrital ages were determined on only a small number of grains. This was done in reconnaissance mode and in this instance a U-Pb calibration was not conducted. For this reason only, ^{207}Pb/^{206}Pb ages are available and it is not possible to evaluate the degree of concordance of the results. The ages reported here assume concordance. The detrital ages range from 2555 to 2748 Ma, with the prominent mode (n=4) at 2660 Ma (Figure GS-11-6a).

Eight high U, oscillatory-zoned zircon rims from sample 8422 were analysed using the ion probe. The data are presented in DRI2006004, Table 2 and shown graphically in Figure GS-11-6b. The weighted mean ^{207}Pb/^{206}Pb age of the rims is 1777 ±17 Ma (2σ, mean standard weighted deviate [MSWD] = 1.4, probability = 0.21).

The zircon metamorphic ages are also supported by monazite TIMS results. Three monazite fractions are between 0.2 and 0.4% discordant, and range from 1769 to 1773 Ma. The three fractions do not overlap within error, suggesting some geological scatter. The results can be found in DRI2006004, Table 2 and Figure GS-11-6b.

Discussion

Detrital zircons from two samples of the Pipe Formation — one at the Pipe II pit, the other at the Thompson mine — contain only Archean zircons. No Paleoproterozoic zircons were identified that would help constrain the maximum age of deposition. Instead, the age of the detritus indicates a source from the Superior craton to the east. The zircons range in age from 2555 to 2934 Ma across both samples, with the dominant age mode at ca. 2.7 Ga. While only a small subset of zircons from the Thompson mine pelite was analyzed, a preliminary conclusion is that the provenance of the pelite and the Pipe II pit semipelite are similar. The single mode at 2.7 Ga is the same as that determined from the Ospwagan Group in earlier studies of a considerably larger combined population that sampled the Ospwagan Group from the bottom to the top (N. Machado, pers comm, 2000; Zwanzig et al., 2001; Hamilton and Bleeker, 2002). These data also provide a maximum age of sedimentation of 2529 Ma from the majority of the sequence or ca. 1974 Ma from a sample high in the stratigraphy (Hamilton and Bleeker, 2002). The unimodal age distribution, which extends laterally along the TNB and vertically throughout the Ospwagan Group, indicates a Neoarchean provenance, probably

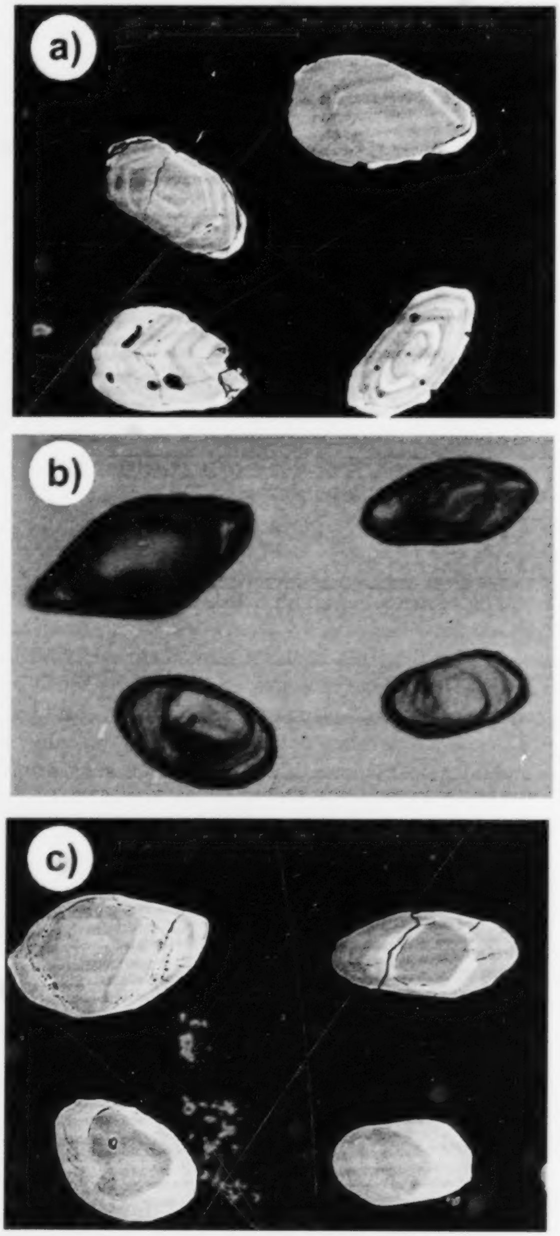
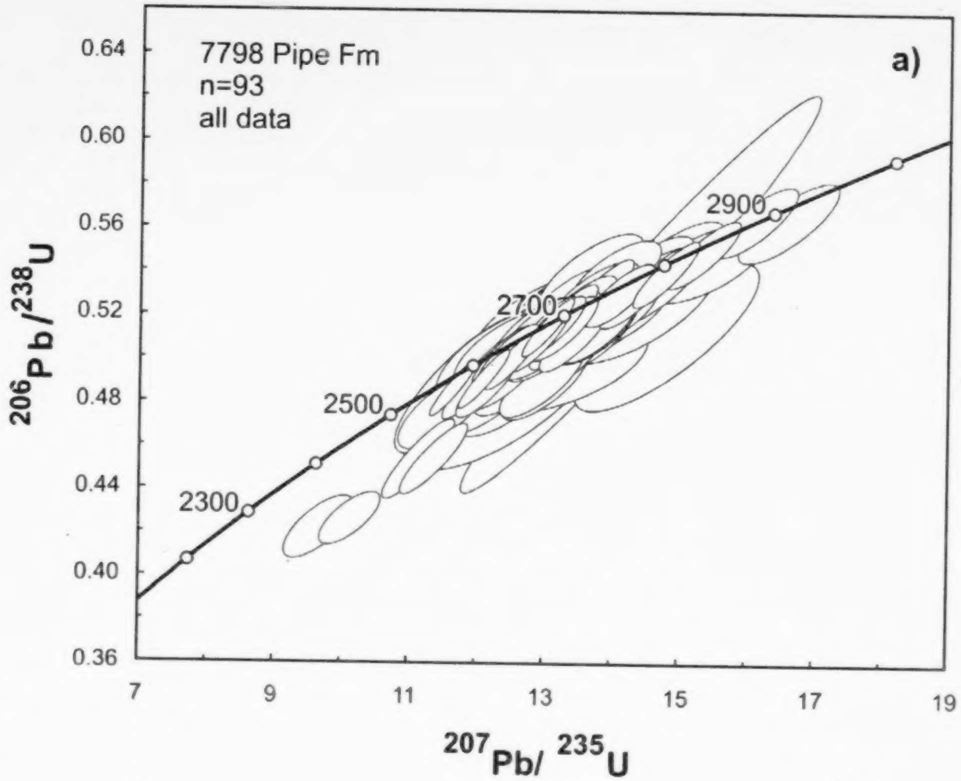


*Figure GS-11-4: Zircon images: **a)** backscattered electron (BSE) image of representative zircon grains from sample 7798 (Pipe II pit). Note thin, high U (bright in BSE) overgrowths on the two upper grains. **b)** Transmitted light image of representative zircon grains from sample 8422 (Inco pelite). Note thick overgrowths around rounded cores. **c)** BSE image of zircons shown in b).*



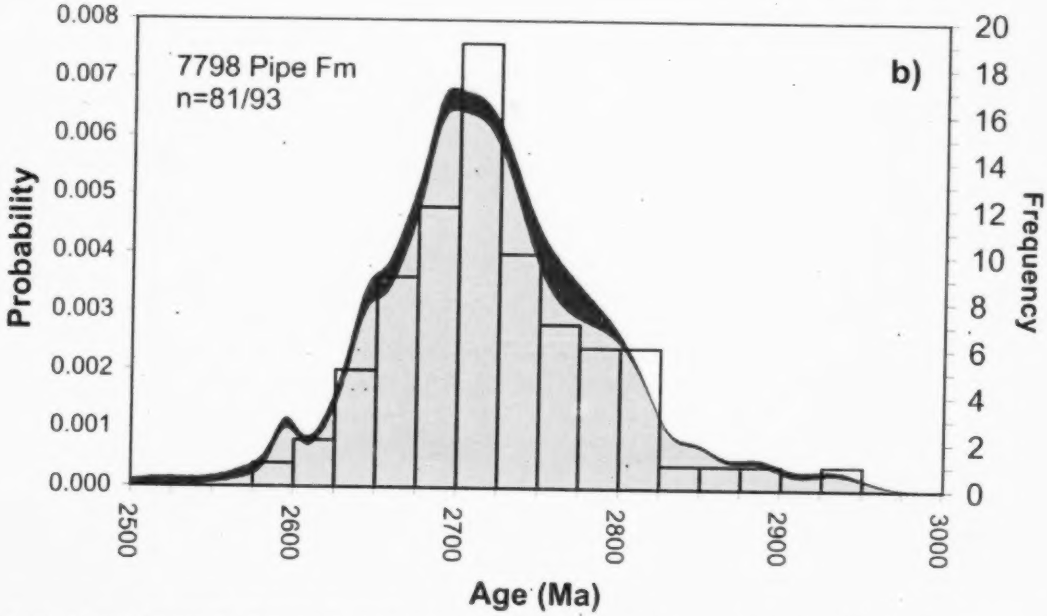


Figure GS-11-5: ***a)*** *Concordia diagram illustrating detrital zircon results for sample 7798 (Pipe II pit). All data (n = 93) are plotted regardless of degree of concordance. Ellipses are plotted at the 2σ uncertainty level.* ***b)*** *Cumulative probability curve and overlying histogram for detrital zircon results for sample 7798. All data is shown by the dark grey curve. Light grey curve and histogram are defined by data that is less than 5% discordant (n = 81).*

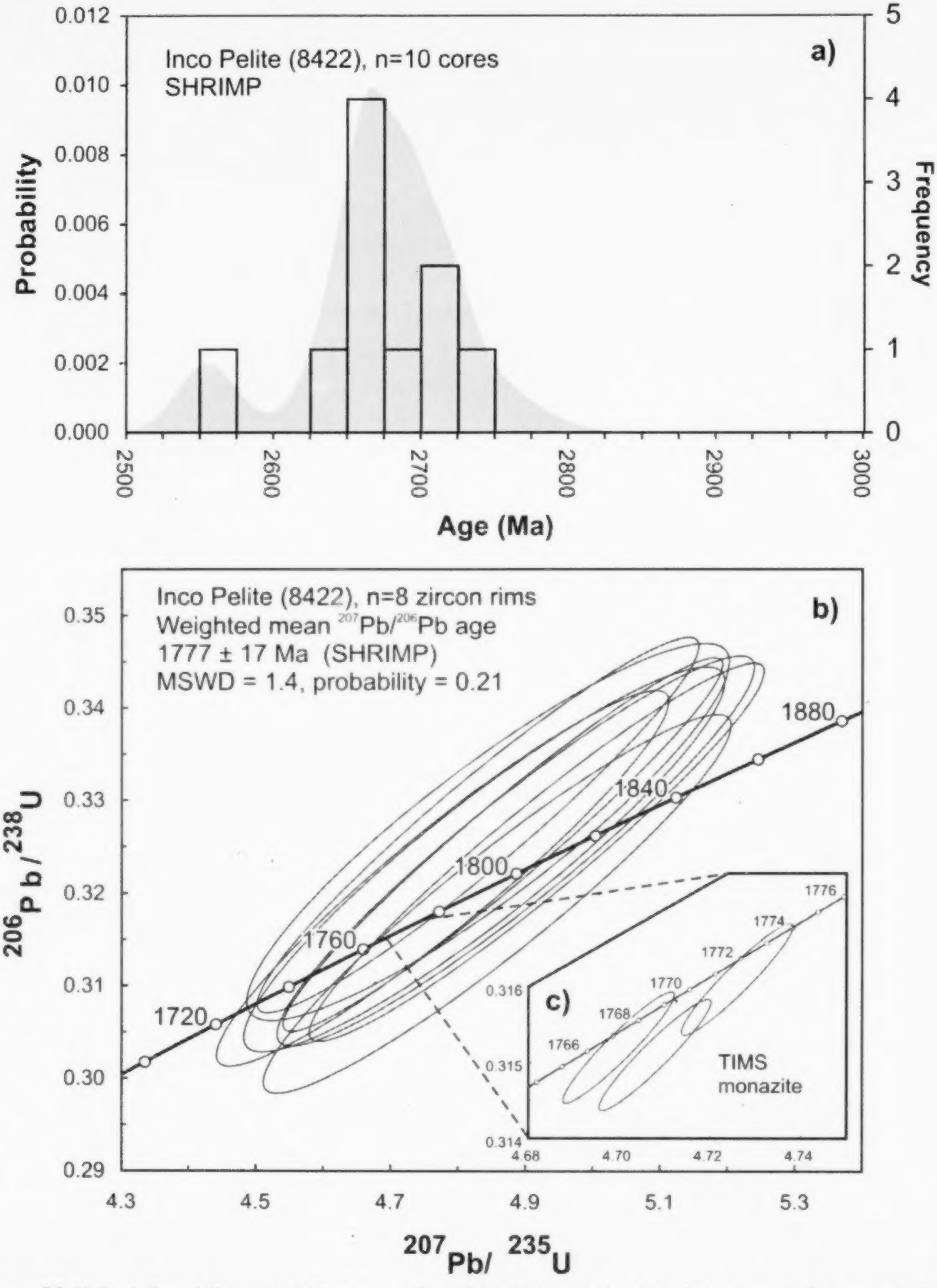


Figure GS-11-6: ***a)*** *Cumulative probability curve and overlying histogram for detrital zircon cores from sample 8422 (pelite, Inco, Thompson mine). All data are included in the plot and are assumed to be concordant.* ***b)*** *Concordia diagram illustrating the timing of metamorphism in sample 8422. Dominant image displays sensitive high-resolution ion microprobe (SHRIMP) results from high-U, low-Th/U overgrowths; inset presents monazite thermal ionization mass spectrometry (TIMS) results.*

from a single terrane. The robust nature of the age distribution suggests that detrital zircon modes are useful in distinguishing the Ospwagan Group from superficially similar rocks that may belong to a different sequence (*see also* Zwanzig et al., GS-9, this volume).

The timing of peak metamorphism with growth of monazite and zircon rims in the Pipe II pit area is ca. 1770 Ma. The rims exhibit low Th/U typical of metamorphic zircon but display oscillatory zoning, which suggests a fluid-mediated reaction. The presence of coeval, late-tectonic pegmatite at Thompson (Machado et al., 1987; Bleeker, 1990a) and across the orogen (Chiarenzelli et al., 1998, Rayner et al., 2005) is consistent with a fluid-rich environment.

Economic considerations

The simple, robust distribution of detrital zircon ages can help to distinguish the nickel-hosting Ospwagan Group from other similar-looking rocks in northern Manitoba and thus delimit areas for further nickel exploration.

Acknowledgments

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GS-12 Preliminary field observations of regional metamorphism in the Thompson Nickel Belt, Manitoba (parts of NTS 63J15, 63O1 and 2, 63O8 and 9, 63P12 and 13)

by C.G. Couëslan[1], D.R.M. Pattison[1] and J.J. Macek

Couëslan, C.G., Pattison, D.R.M. and Macek J.J. 2006: Preliminary field observations of regional metamorphism in the Thompson Nickel Belt, Manitoba (parts of NTS 63J15, 63O1 and 2, 63O8 and 9, 63P12 and 13); *in* Report of Activities 2006, Manitoba Science, Technology, Energy and Mines, Manitoba Geological Survey, p. 125–135.

Summary

Field investigations have been carried out on the Hudsonian metamorphism of supracrustal rocks in the Thompson Nickel Belt (TNB). Outcrops were examined throughout the exposed portions of the belt for mineral assemblages useful for temperature-pressure determination. Orthopyroxene was identified in Ospwagan Group sedimentary rocks from Nichols and Phillips lakes and may also be present in garnet-bearing metagabbro at the Thompson mine, suggesting granulite-grade metamorphism (≥800°C, uncertain pressure). Potassium-feldspar-bearing metasedimentary rocks from the Hambone and Setting lakes areas contain sillimanite intergrown with biotite along the foliation and an absence of muscovite, suggesting grades of upper amphibolite facies. Sillimanite is common as discrete knots at Setting and Mid lakes. At Moak Lake, sillimanite knots contain possible andalusite cores, suggesting conditions near the andalusite-sillimanite phase transition and middle amphibolite facies grade. Metasedimentary rocks at Ospwagan Lake are also found to be andalusite bearing. Staurolite- and andalusite-bearing metapelite (middle amphibolite facies) and nonmigmatitic K-feldspar- and sillimanite-bearing metapelite (upper amphibolite facies) are present in proximity to one another at the Pipe mine. This makes interpretation of metamorphic conditions difficult, although both assemblages indicate pressures of 3.5 to 4 kbar. The distribution of higher grade and lower grade rocks suggests that grades may be higher along the eastern side and southern end of the belt, and lower along the western side and northern end of the belt.

The creation of a comprehensive tectonic model for the TNB has been hampered by a lack of metamorphic data. This is important both for a greater understanding of the Trans-Hudson Orogen in Manitoba and for exploration strategies within the TNB. The local grade of regional metamorphism may have an effect on the mobilization of orebodies through solid state, hydrothermal and anatectic processes. In addition, the character of Ospwagan Group metasedimentary rocks may vary greatly depending on metamorphic grade. These metasedimentary rocks are known to host the most significant nickel deposits in the belt, and documentation of this metasedimentary group at various grades will provide an additional tool for mineral exploration. This is a preliminary look into the Hudsonian metamorphism of the TNB as part of an ongoing Ph.D. study.

Introduction

The 400 km long by 10 to 35 km wide, northeast-trending Thompson Nickel Belt (TNB) occurs along the northwestern margin of the Superior craton (Bleeker, 1990a; Hulbert et al., 2005; Figure GS-12-1). As part of the Superior Boundary Zone, the TNB marks a segment of the collisional zone between the Superior craton and the juvenile terranes of the Trans-Hudson Orogen. The TNB begins 70 km northeast of Thompson (Zwanzig, 2005) and continues southwest, with half of its total length covered by Phanerozoic rocks. Its southeastern margin, in the northern exposed portion, is gradational with the Pikwitonei Granulite Domain. Its northwestern margin is bounded by the Kisseynew Domain of the Trans-Hudson Orogen internal zone.

The TNB is dominated by variably reworked Archean basement gneiss with minor Paleoproterozoic supracrustal and intrusive rocks (Bleeker 1990a, 1990b; Weber, 1990; Hulbert et al., 2005). The Archean basement consists largely of migmatitic gneiss that is believed to be derived from retrogressed Pikwitonei granulite (Russell, 1981; Bleeker, 1990b; Machado et al., 1990; Weber, 1990; Lettley, 2001). The Archean basement gneiss is unconformably overlain by metasedimentary and metavolcanic rocks of the Paleoproterozoic Ospwagan Group (Bleeker and Macek, 1988a; Bleeker, 1990a, 1990c). The supracrustal rocks occur in deeply dissected, regional-scale folds or fault slices (Bleeker, 1990a; Weber, 1990).

The Ospwagan Group supracrustal sequence consists, from base to top, of the Manasan Formation, Thompson Formation, Pipe Formation, Setting Formation and Bah Lake volcanogenic assemblage (Bleeker and Macek, 1988a; Bleeker, 1990a, 1990c; Zwanzig et al., work in progress, 2006). The Manasan Formation is a clastic sequence that consists of M1 member quartzite with local conglomerate, overlain by M2 member semipelite. The Manasan Formation clastic rocks grade into the overlying Thompson Formation, which consists dominantly of calcsilicate and siliceous dolomite. The Pipe

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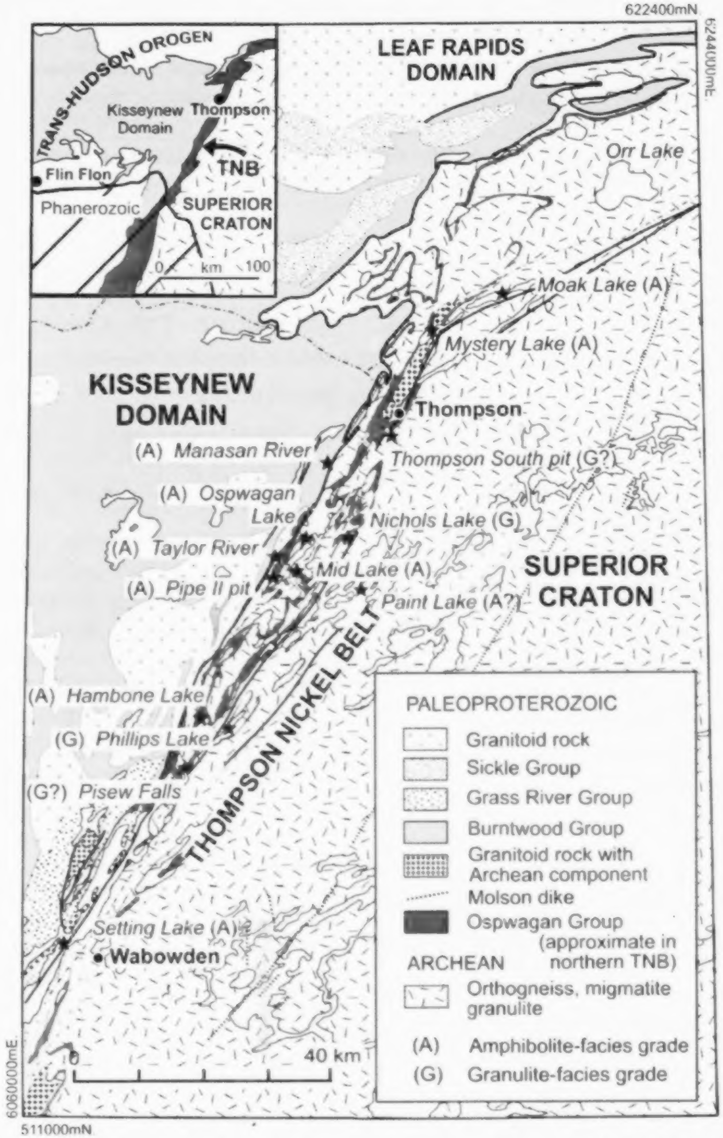
622400mN
6244000mE
LEAF RAPIDS DOMAIN
TRANS-HUDSON OROGEN
Kisseynew Domain
Thompson
Flin Flon
TNB
Phanerozoic
SUPERIOR CRATON
0 km 100
Orr Lake
Moak Lake (A)
Mystery Lake (A)
KISSEYNEW DOMAIN
Thompson
(A) Manasan River
Thompson South pit (G?)
(A) Ospwagan Lake
Nichols Lake (G)
(A) Taylor River
Mid Lake (A)
(A) Pipe II pit
Paint Lake (A?)
SUPERIOR CRATON
THOMPSON NICKEL BELT
(A) Hambone Lake
(G) Phillips Lake
(G?) Pisew Falls
Setting Lake (A)
Wabowden
0
40 km
6060000mE
511000mN
PALEOPROTEROZOIC
Granitoid rock
Sickle Group
Grass River Group
Burntwood Group
Granitoid rock with Archean component
Molson dike
Ospwagan Group (approximate in northern TNB)
ARCHEAN
Orthogneiss, migmatite granulite
(A) Amphibolite-facies grade
(G) Granulite-facies grade

***Figure GS-12-1:** Tectonic setting and regional geology of the exposed portion of the Thompson Nickel Belt (after Zwanzig, 2005), showing general locations of study areas.*

Formation consists of three members. The P1 member directly overlies Thompson Formation calcareous rocks and consists of sulphide- and silicate-facies iron formation, chert, and siliceous and ferruginous sedimentary rocks. The P2 member consists of a pelitic schist. It contains aluminous horizons that may contain garnet, staurolite and/or Al_2SiO_5. Above the P2 pelite are siliceous sedimentary rocks, ferruginous sedimentary rocks, iron formation, marble and calcsilicate of the P3 member. The Setting Formation consists of interlayered pelitic schist and quartzite with pink, garnet- and carbonate-bearing lenses. The Bah Lake assemblage consists of mafic to ultramafic volcanic flows with abundant dikes and sills (Zwanzig, 2005).

Quartzite and conglomerate of the Grass River Group unconformably overlie the Bah Lake assemblage (Zwanzig et al., work in progress, 2006). The basal polymictic conglomerate of the Grass River Group contains clasts that range in composition from ultramafic to felsic. Above the basal conglomerate is a lower, hornblende-bearing arkosic metasandstone, which grades into biotite- and magnetite-bearing arkosic metasandstone. The Grass River Group is interpreted to be the shallow-water facies of the Burntwood Group of the Kisseynew Domain (Zwanzig et al., work in progress, 2006). Burntwood Group rocks locally display rhythmic layering that is interpreted to be preserved, but metamorphically recrystallized, primary greywacke to mudstone turbidite beds (Zwanzig et al., work in progress, 2006). Ospwagan Group and Burntwood Group rocks are brought into contact only along major faults.

Few metamorphic studies have been undertaken in the TNB and they have generally been restricted to local investigations. A number of studies have been conducted at the Thompson mine. Paktunç (1984) determined a temperature of 700°C and a pressure of 4.8 kbar using spinel-olivine geothermometry and mineral assemblages present in an ultramafic body. Bleeker (1990a) found similar temperatures of 700 to 750°C using garnet-biotite geothermometry; however, pressures were found to be 6 to 7 kbar using garnet-sillimanite-quartz-plagioclase geobarometry. Bleeker (1990c) also investigated metamorphic conditions at the Birchtree mine and Ospwagan Lake. At the Birchtree mine, a temperature of 680°C was obtained with a pressure of 5 to 6 kbar, whereas the temperatures at Ospwagan Lake were considerably lower (530 to 575°C). Investigations by Russell (1981) at Paint Lake suggested peak Hudsonian metamorphic conditions of 650 ±50°C and 4 to 5 kbar using garnet-biotite geothermometry and garnet-sillimanite-quartz-plagioclase geobarometry. The peak metamorphic conditions at the Pipe mine were constrained using metamorphic assemblages by Fueten and Robin (1989) to be 575 to 625°C, and by Bleeker (1990a) to be 600 to 660°C and 5 to 6 kbar using garnet-biotite geothermometry and garnet-sillimanite-quartz-plagioclase geobarometry. Overall, metamorphic conditions in the areas observed in this study are interpreted to range from middle amphibolite facies to lower granulite facies of low to moderate pressures. This preliminary report is part of an ongoing Ph.D. study into the Hudsonian metamorphism of the TNB.

Methodology

Pre-existing geological maps were used to select outcrops of greatest potential for petrological studies. These outcrops, consisting largely of Ospwagan Group supracrustal rocks, include pelitic to semipelitic rocks, iron formation, amphibolite and calcsilicate rocks. Such rock types are most likely to yield favourable mineral assemblages for pressure and temperature determination using classical metamorphic petrology and thermodynamic modelling. Most of the outcrops were located along lakeshores and at two past-producing open-pit mines operated by Inco Limited.

Diamond-drill core, obtained from Inco Technical Services Limited, was examined from areas with poor accessibility and/or outcrop exposure. Drillholes were selected based on old core logs and current geological maps. The core had been previously condensed by sampling 6-inch lengths of core every 10 feet. Samples with mineral assemblages useful for petrological and thermodynamic studies were collected for thin sectioning.

Thompson mine South pit

The southwest shoulder of the Thompson mine South pit (Figure GS-12-1) was examined using the recent map of Macek et al. (2005). The textures and mineralogy of the various rock types were investigated in detail. Muscovite is abundant throughout the groundmass of the M2 semipelite; however, the presence of sillimanite and ubiquitous K-feldspar-bearing leucosome, which appear to be of in situ origin, suggests temperatures likely surpassed the stability field of muscovite and caused melting (Figure GS-12-2). The sillimanite knots, and occasionally feldspar within the leucosome, may be strongly overprinted by fine-grained muscovite (Couëslan, 2003), suggesting that much of the muscovite in the semipelite may be retrograde and likely related to the release of H_2O during crystallization of the melt

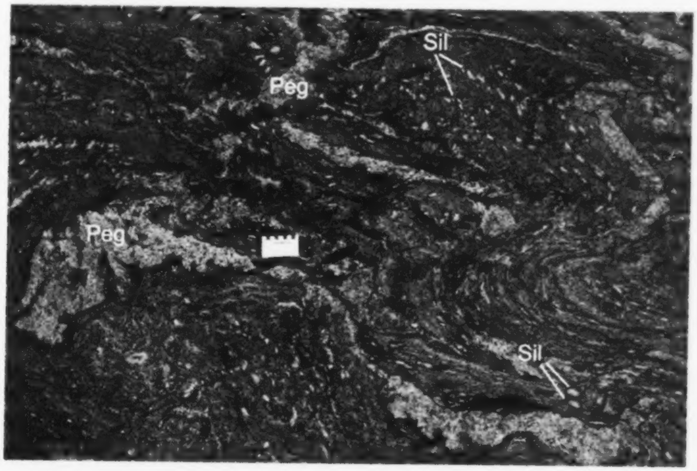

Figure GS-12-2: *Sillimanite knots and pegmatite sweats in Manasan Formation M2 semipelite at the Thompson mine South pit. The pegmatitic material appears to be in situ. The scale card is in centimetres. Abbreviations: Peg, pegmatite; Sil, sillimanite.*

(Spear et al., 1999). Field observations and detailed sampling revealed the garnet-bearing leucoamphibolite core of a metagabbro dike to be of greatest interest for metamorphic studies. Local pods of in situ leucosome within the amphibolite appear to originate from partial melting, possibly in the presence of an anhydrous fluid (Figure GS-12-3). In addition to quartz and feldspar, the leucosome is often characterized by very coarse grained anhedral garnet, blocky hornblende, diopside and what has tentatively been identified in the field as orthopyroxene. Bleeker (1990c) also reported orthopyroxene, which he interpreted to be metamorphic, in an ultramafic amphibolite at Thompson. If the orthopyroxene is, in fact, present, the metamorphic grade at the Thompson mine must have attained at least lower granulite grade.

Pipe mine open pit

Utilizing the detailed maps of Bleeker and Macek (1988b–e), lithological units at the Pipe mine (Figure GS-12-1) were examined in detail for mineral assemblages and textures. Detailed sampling of Ospwagan Group pelite and iron formation was conducted at outcrops to the east and north of the open pit.

Coarse-grained andalusite, wrapped by foliation, is present along with staurolite, muscovite, and biotite in the Pipe Formation P2 pelite exposure just north of the open pit (Figure GS-12-4). Whereas Bleeker (1990c) interpreted the andalusite at the Pipe mine as retrograde, the authors' observations suggest it occurs as primary porphyroblasts. Locally, staurolite porphyroblasts are rimmed with muscovite. Sillimanite occurs in pelitic horizons of the Setting Formation and in the easternmost exposures of the P2 pelite and M2 semipelite. In rocks of the Setting Formation, the sillimanite occurs as the discrete knots or rods recognized by Bleeker (1990c), which in some instances are characterized by blocky outlines. The occurrence of sillimanite in discrete, sometimes blocky, rod-like segregations, rather than intergrown with biotite within the foliation, suggests that sillimanite may be pseudomorphous after andalusite or possibly staurolite (Figure GS-12-5). This is supported by the observation of darkened cores in many of the sillimanite knots, suggestive of relict andalusite or possibly staurolite.

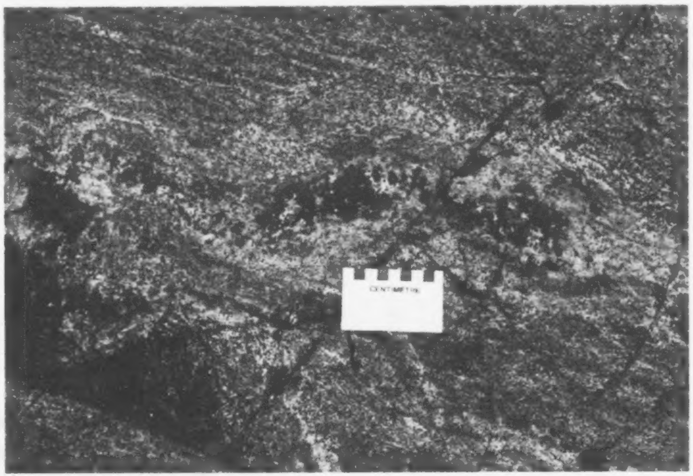

Figure GS-12-3: Leucosome in garnet-bearing leucoamphibolite at the Thompson mine South pit. Coarse-grained mafic minerals found in the core of the leucosome consist dominantly of garnet, hornblende, diopside and a mineral that has been tentatively identified as orthopyroxene.

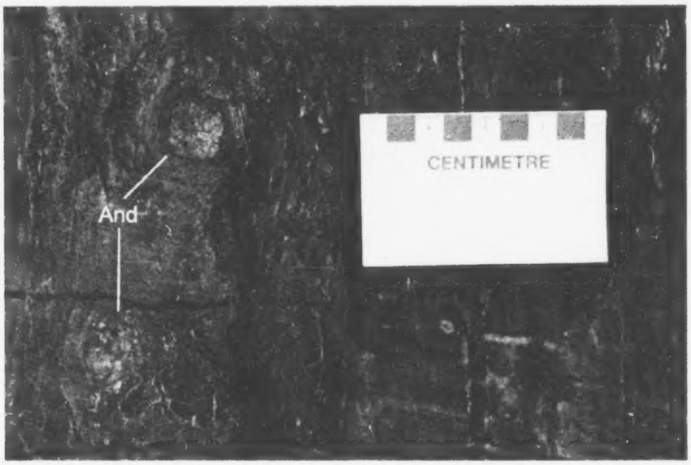

Figure GS-12-4: Coarse-grained andalusite porphyroblasts in Pipe Formation P2 pelite at the Pipe mine open pit. The groundmass also contains staurolite. Abbreviation: And, andalusite.

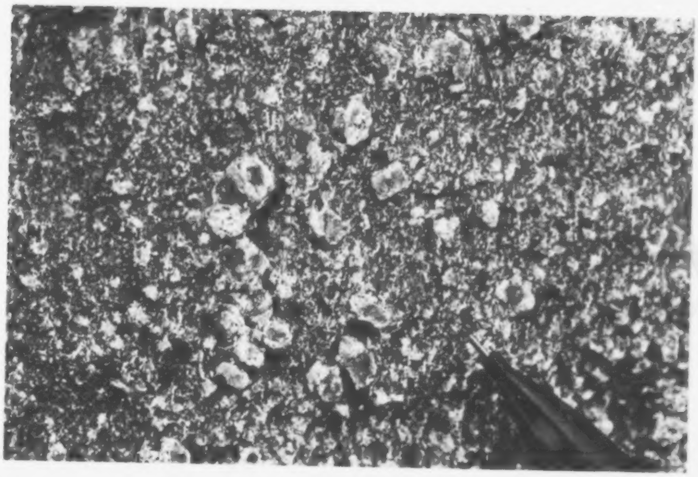

Figure GS-12-5: *Sillimanite knots in Setting Formation sillimanite-biotite gneiss at the Pipe mine open pit. The sillimanite knots are characterized by darkened cores and frequently have a blocky habit, suggesting they may have pseudomorphically replaced andalusite or staurolite. Note the absence of leucosome development.*

Prior to the 2006 summer field season, thin sections of Pipe Formation silicate-facies iron formation and Setting Formation sillimanite-biotite gneiss were examined in a preliminary study. The iron formation contains the prograde metamorphic assemblages fayalite-garnet-hornblende-grunerite-magnetite and fayalite-diopside-magnetite-grunerite-garnet. Ferrosilite is also commonly observed in the iron formation, and many grains show retrograde alteration to grunerite. The Setting Formation sillimanite-biotite gneiss contains abundant microcline, quartz and biotite, and is sillimanite and muscovite bearing. The microcline occurs as coarse-grained poikiloblasts with inclusions of biotite, tourmaline, muscovite and quartz (Figure GS-12-6). The sillimanite forms discrete fibrous knots, whereas the muscovite commonly forms discrete, coarse, tabular grains and is occasionally interleaved with biotite within the foliation. Outcrops of the gneiss display no signs of leucosome development (Figure GS-12-5). Although the presence of abundant microcline along with sillimanite suggests temperatures exceeded the stability field for muscovite, a lack of leucosome suggests that melting did not occur. This requires pressures low enough for the muscovite reaction to proceed under subsolidus conditions.

Mineral assemblages observed in the P2 pelite during field studies suggest middle amphibolite facies metamorphic conditions within the rather narrow stability field of co-existing andalusite and staurolite (~570–580°C and 3.8–4.2 kbar; Figure GS-12-7). Blocky sillimanite in rocks 200 m to the west suggests that this field may have been overstepped into the stability field of sillimanite. The relatively broad field defined by the mineral assemblages present in the iron formation is in agreement with a slight overstepping into the field of stable sillimanite.

The assemblage in the Setting Formation gneiss indicates pressure conditions similar to those in the andalusite- and staurolite-bearing P2 pelite (3.5–3.7 kbar); however, it suggests much greater (upper amphibolite facies) temperatures (640–650°C; Figure GS-12-7).

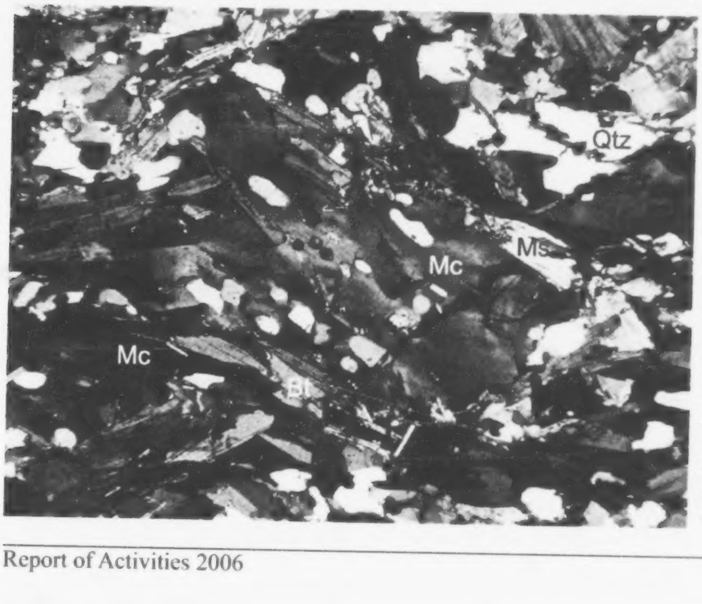

Figure GS-12-6: *Photomicrograph in cross-polarized light of poikiloblastic microcline in Setting Formation sillimanite-biotite gneiss from the Pipe mine. The field of view is 2.6 mm. Abbreviations: Bt, biotite, Mc, microcline, Ms, muscovite, Qtz, quartz.*

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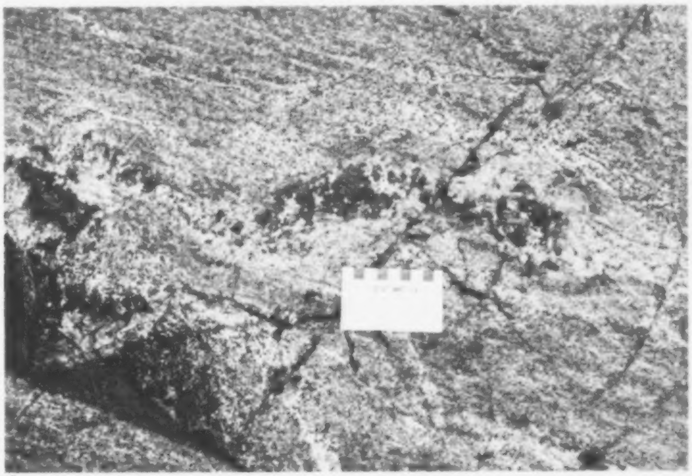

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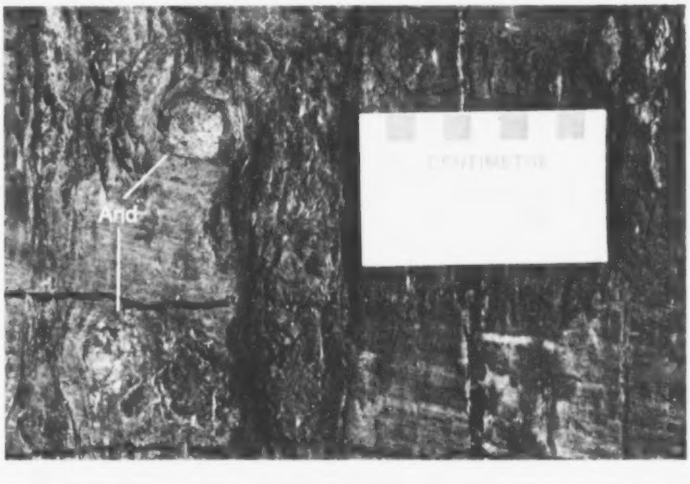

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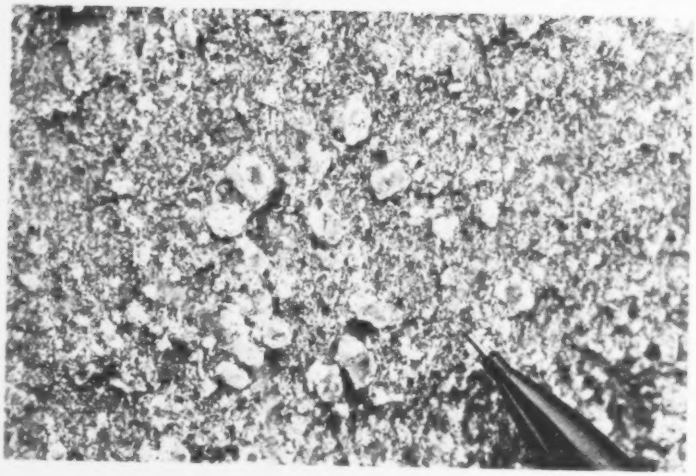

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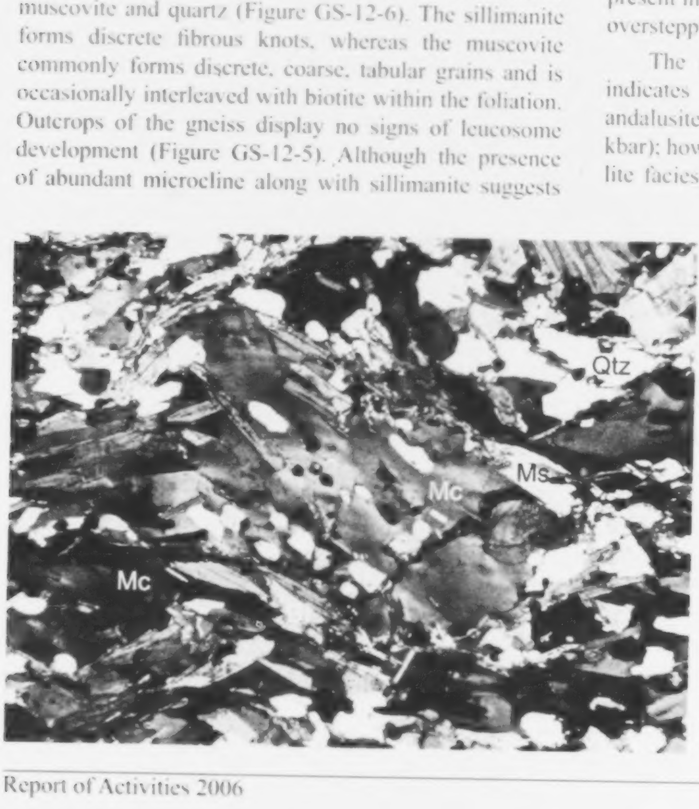

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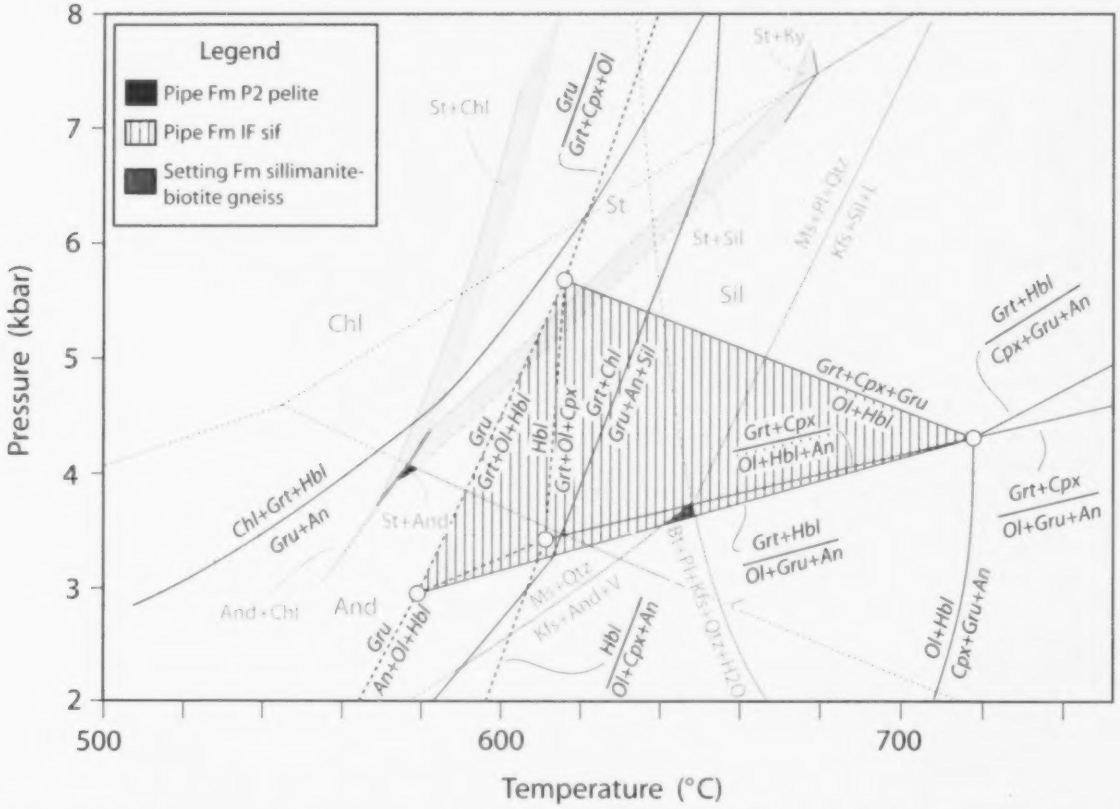

Figure GS-12-7: *Petrogenetic grid showing the metamorphic conditions for mineral assemblages found in pelite and iron formation at the Pipe mine. The phase relationships in black lines are in the systems* CaO*-*FeO*-*MgO*-*Al_2O_3*-*SiO_2*-*H_2O *(solid lines) and* CaO*-*FeO*-*Al_2O_3*-*SiO_2*-*H_2O *(broken lines) from Zeh et al. (2005) for iron formations, and the grey lines are for average pelite in the system* K_2O*-*FeO*-*MgO*-*Al_2O_3*-*SiO_2*-*H_2O *(Pattison and Vogl, 2005), Broken lines represent metastable assemblages. The reaction curves Ms + Pl + Qtz ↔ Kfs + Sil + L and Bt + Pl + Kfs + Qtz + H2O ↔ L come from Pattison et al. (2003). Abbreviations: An, anorthite; And, andalusite; Bt, biotite; Chl, chlorite; Cpx, clinopyroxene; Grt, garnet; Gru, grunerite; Hbl, hornblende; Kfs, K-feldspar; Ky, kyanite; L, liquid (melt); Ms, muscovite; Ol, olivine; Pl, plagioclase; Qtz, quartz; Sil, sillimanite; St, staurolite; V, vapour.*

The possibility of higher temperatures is also supported by the presence of Fe-Mg-amphibole and calcic amphibole pairs with exsolution lamellae. The occurrence of Fe-Mg-amphibole–calcic amphibole pairs displaying exsolution lamellae is characteristic of upper amphibolite to lower granulite facies (Deer et al., 1997).

The discrepancy in temperature indicated by the mineral assemblages at the Pipe mine is difficult to interpret. One possibility is the presence of a fault between the two locations; however, the continuity of units within the Ospwagan Group argues against great lateral displacement, and the similarities in pressures between the two mineral assemblages argue against significant vertical offset. Another possibility is the metastable persistence of andalusite and staurolite above the temperatures that define their stability range. Resolving this issue will be the subject of further research.

Natural outcrops

Outcrops were investigated along the shores of Mystery, Ospwagan, Paint and Setting lakes, as well as along the banks of the Manasan, Taylor and Grass rivers (Figure GS-12-1). Another outcrop locality was also visited near Mid Lake.

Mystery Lake

Outcrops of Burntwood Group garnet-biotite gneiss and Ospwagan Group M2 semipelite, P2 pelite and Setting Formation rocks were described and sampled at Mystery Lake. All rocks are intensely sheared and variably retrogressed, likely the result of proximity to the Mystery Lake Fault. The Burntwood Group gneiss is composed of alternating bands of metagreywacke and pelitic schist, and is migmatitic and highly sheared. Ribbon quartz and mylonitic textures are common, and veins of pseudotachylite are locally present. Quartz-rich segregations within the gneiss contain coarse-grained cordierite porphyroblasts. Staurolite is present locally within more aluminous horizons.

The Pipe Formation P2 pelite has been intruded by and infolded with a metadiabase dike, assumed to be of the Molson swarm. The pelite consists of highly sheared, fine-grained schist, and intensely folded ribbon quartz is common. The intensely infolded and sheared Molson dike is generally garnet rich along the contact with the pelite.

The Setting Formation rocks consist dominantly of quartzite with intercalations of pelitic schist. The rocks have been intensely folded and sheared, giving the quartzite the appearance of a siliceous mylonite. The pelite may be retrogressed, as it appears to be enriched in fine-grained chlorite.

Ospwagan Lake

A succession of Ospwagan Group supracrustal rocks from the Pipe Formation to the Bah Lake assemblage was studied at Niven Point on Lower Ospwagan Lake. Here, the P2 pelite is a muscovite schist that locally contains coarse-grained andalusite porphyroblasts in cherty horizons. A horizon of Bah Lake assemblage metabasalt with garnet- and plagioclase-bearing stringers occurs at the northeast corner of Upper Ospwagan Lake.

Taylor and Manasan rivers

Outcrops of Burntwood Group garnet-biotite gneiss were examined upstream and downstream from Lower Ospwagan Lake along the Taylor and Manasan rivers, respectively. The Burntwood Group gneiss is migmatitic and composed of metagreywacke with intercalations of metapelitic schist. Along the Taylor River, the Burntwood Group rocks are retrogressed with abundant pinitized cordierite. The cordierite in the Manasan River outcrops, although less common, appears to be relatively unaltered. Pelitic horizons in the Manasan River outcrops are locally sillimanite rich. The sillimanite occurs intergrown with the biotite within the foliation.

Paint Lake

The outcrops studied on Paint Lake consist of both Archean basement rocks and Proterozoic Ospwagan Group rocks. An outcrop of M2 semipelite, exposed in a roadcut at the marina on Paint Lake, is characterized by pods of mobilizate that appear to have been generated in situ. The leucosome occurs at all scales in the rock and is pooled between primary compositional layering (Figure GS-12-8), suggestive of temperatures above minimum melting.

Two samples of Archean metapelitic rocks were sampled and described from the northeastern and central parts of the lake. The pelite is characterized by very coarse grained garnet and discrete prismatic grains of aluminosilicate. The aluminosilicate appears to be sillimanite pseudomorphous after kyanite. The former presence of kyanite is attributed to higher pressures attained by the Archean rocks prior to the Trans-Hudson orogeny. A sample was also obtained of garnet-bearing enderbite from the southeastern portion of the lake.

Mid Lake

Outcrops of Bah Lake assemblage metabasalt and Setting Formation quartzite are present in an inactive clay quarry just south of the Mid Lake exit on Highway 6. At this location, metasedimentary rocks at the top of the Setting Formation are infolded with metavolcanic rocks at the base of the Bah Lake assemblage. The Setting Formation rocks consist dominantly of quartzite with intercalations of pelitic schist. The schist contains sillimanite as flattened knots within the foliation. The Bah Lake assemblage metabasalt consists of pillowed flows. At the contact between the Setting Formation and the Bah Lake assemblage, the bottom 30 cm of the metabasalt is garnet bearing.

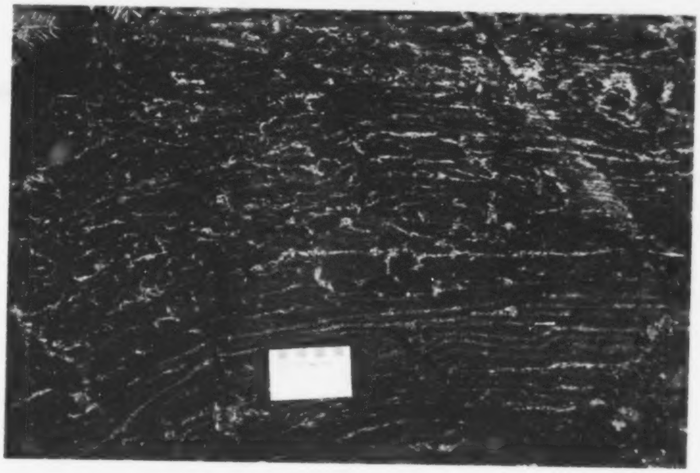

Figure GS-12-8: *Leucosome in Manasan Formation M2 semipelite at Paint Lake appears to be in situ. The pegmatitic material appears to be pooling between primary compositional layering in the rock and the primary bedding has begun to be disrupted by the melt. The scale card is in centimetres.*

Grass River

Metabasalt of the Bah Lake assemblage was investigated at two localities along the Grass River: west of Kwasitchewan Falls and above Pisew Falls. The metabasalt here is characterized by pods of sheared pillow selvages, interpillow material and/or mobilizate. The pods are generally rich in quartz and feldspar, and contain variable amounts of coarse-grained hornblende, diopside, garnet, carbonate and a blocky, brown-weathering mineral that is green on freshly exposed surfaces; although not positively identified, the mineral is likely either diopside or orthopyroxene. Further petrographic studies will be conducted.

Setting Lake

Metasedimentary rocks of the Grass River Group, Ospwagan Group and Burntwood Group were described and sampled from the northern, central and southern portions of Setting Lake. Rocks of the Grass River Group consist of a polymictic metaconglomerate and meta-arkose. Sillimanite-bearing meta-arkosic rocks occur in both central and northern portions of the lake, with the sillimanite occurring in discrete medium- to coarse-grained knots in the fine-grained arkosic groundmass.

Burntwood Group and Setting Formation rocks occur in the southern portion of the lake. The Setting Formation rocks consist dominantly of quartzite with intercalations of pelitic schist. The pelitic horizons are sillimanite rich. The entire unit has been intruded by pink pegmatite dikes that commonly contain rafts and schlieren derived from the Setting Formation rocks. The largest of these pegmatite dikes have an approximate north trend. The Burntwood Group rocks consist largely of garnet-biotite gneiss, interpreted to be metagreywacke, and contain semiconformable pods of quartzofeldspathic mobilizate.

Diamond-drill core

Drillcore was examined from areas near Moak, Mystery, Nichols, Liz, Hambone, Phillips, and Setting lakes (Figure GS-12-1). Pipe Formation P2 pelite in two separate drillholes from the Moak Lake area contains discrete, coarse-grained sillimanite knots with pinkish brown cores. The pinkish brown cores may be relict andalusite, suggesting metamorphic conditions near the andalusite-sillimanite phase transition. Muscovite is also abundant in the pelite, and porphyroblasts of staurolite were noted in several horizons.

Orthopyroxene was identified in Ospwagan Group metasedimentary rocks in core from Nichols and Phillips lakes. The orthopyroxene is found in biotite paragneiss and impure chert, and implies granulite-grade metamorphism.

Core from the Hambone Lake and Setting Lake areas contains sillimanite as discrete knots and intergrown with biotite within the foliation. No muscovite was noted.

Conclusions

Preliminary investigation suggests that metamorphic conditions in the Thompson Nickel Belt (TNB) during the Trans-Hudson orogeny may have reached higher grades, over greater areas, than previously recognized (Figure GS-12-1). Proterozoic rocks within the TNB have been subjected to metamorphic grades ranging from middle amphibolite to granulite facies, with no prograde greenschist-facies assemblages observed (Figure GS-12-9). Granulite-grade rocks (≥800°C, uncertain pressure) are recognized at Nichols and Phillips lakes, and may also be present at the Thompson mine and along the Grass River near Pisew and Kwasitchewan falls. Ospwagan Group rocks at Hambone Lake and Setting Lake have surpassed the limit of muscovite+quartz stability (upper amphibolite grade). Metamorphic conditions exceeded those required to produce melts at the Thompson mine and the Paint Lake marina (upper amphibolite grade). At Moak Lake, metamorphic conditions appear to be middle amphibolite grade, near the andalusite-sillimanite phase transition but within the stability field of muscovite+staurolite (~550–600°C, 3.5–4 kbar). At Ospwagan Lake, the presence of andalusite and muscovite suggests similar middle amphibolite facies conditions. Staurolite- and andalusite-bearing metapelite (middle amphibolite facies) and nonmigmatitic K-feldspar- and sillimanite-bearing metapelite (upper amphibolite facies) are present close to one another at the Pipe mine. This makes interpretation of metamorphic conditions difficult, although both assemblages indicate pressures of 3.5 to 4 kbar. The overall pattern for the TNB is that metamorphic grades are higher along the eastern side of the belt (Phillips and Nichols lakes) and lower along the western side of the belt (Ospwagan and Moak lakes), with some evidence for increasing grades to the south at Setting Lake.

Economic considerations

Better understanding of regional metamorphic data for the Thompson Nickel Belt will aid development of a regional tectonic framework for the belt. This is important for both a greater understanding of the Trans-Hudson Orogen in Manitoba and for exploration strategies within the TNB. The local grade of regional metamorphism may also be important, as it may have an effect on the mobilization of orebodies through solid-state, hydrothermal and anatectic processes. Finally, metamorphic grade affects the characteristics of Ospwagan Group supracrustal rocks (Zwanzig et al., work in progress, 2006). A thorough documentation of their characteristics at different metamorphic grades will greatly increase the ability to recognize Ospwagan Group rocks that have been metamorphosed. This is significant for exploration in the TNB, because the most significant nickel deposits in the belt occur within the P1 and P2 members of the Pipe Formation.

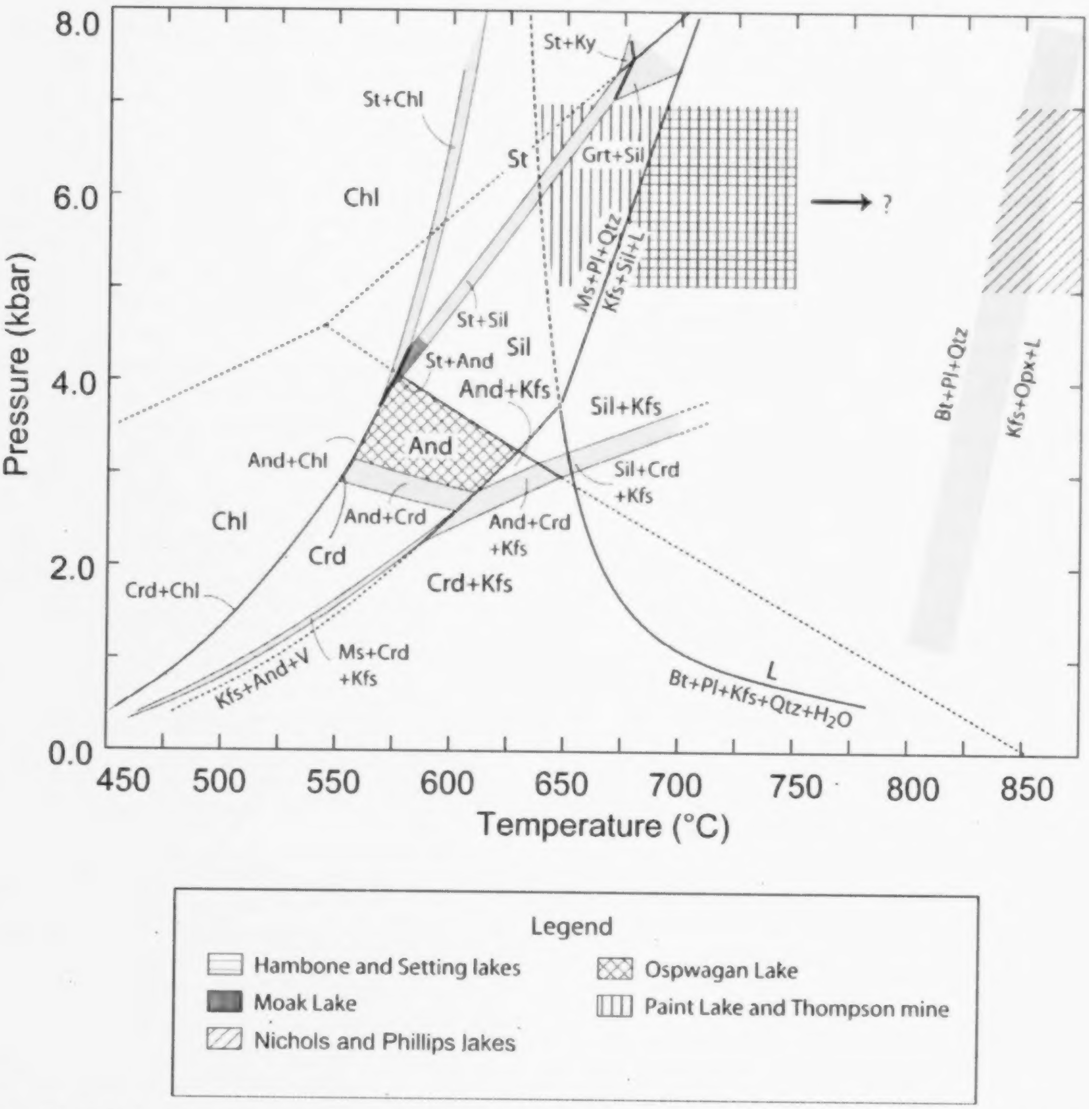

Figure GS-12-9: *Petrogenetic grid for pelite of average composition in the system* K_2O*-FeO-MgO-*Al_2O_3*-*SiO_2*-*H_2O *(Pattison and Vogl, 2005). The reaction curves Ms + Pl + Qtz ↔ Kfs + Sil + L; Bt + Pl + Kfs + Qtz +* H_2O *↔ L; and Bt + Pl + Qtz ↔ Kfs + Opx + L come from (Pattison et al., 2003), with the Opx-producing reaction relevant to semipelitic rather than pelitic bulk compositions. Assemblages have been plotted for pelitic and semipelitic rocks observed at Hambone Lake, Moak Lake, Nichols Lake, Ospwagan Lake, Paint Lake, Phillips Lake, the Pipe mine, Setting Lake and the Thompson mine. The pressures depicted by the fields for Hambone and Setting lakes, Nichols and Phillips lakes, and Paint Lake and the Thompson mine are constrained by the geobarometric work of Bleeker (1990c), although it is probable that the pressures were lower. Abbreviations: And, andalusite, Bt, biotite, Chl, chlorite, Crd, cordierite, Grt, garnet; Kfs, K-feldspar, Ky, kyanite, L, liquid, Ms, muscovite, Opx, orthopyroxene; Pl, plagioclase, Qtz, quartz, Sil, sillimanite, St, staurolite, V, vapour.*

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GS-13 Preliminary results from geological bedrock mapping of the Kasmere and Putahow lakes areas, northwestern Manitoba (parts of NTS 64N6, 10, 11 and 15)

by C.O. Böhm and S.D. Anderson

Böhm, C.O. and Anderson, S.D. 2006: Preliminary results from geological bedrock mapping of the Kasmere and Putahow lakes areas, northwestern Manitoba (parts of NTS 64N6, 10, 11 and 15); *in* Report of Activities 2006, Manitoba Science, Technology, Energy and Mines, Manitoba Geological Survey, p. 136–147.

Summary

As part of the Manitoba Geological Survey's initiative to update the geological knowledge base of Manitoba's far north, field investigations in 2006 were focused on the Kasmere and Putahow lakes areas. Detailed bedrock mapping and sampling were undertaken for lithogeochemical, isotope geochemical and geochronological studies to improve the currently limited understanding of the nature and evolution of this portion of Manitoba's Precambrian shield, and to support ongoing uranium and gold exploration in the area. In this report, bedrock exposures at Kasmere and Putahow lakes are described and subdivided into 1) metasedimentary rocks of the Paleoproterozoic Wollaston Domain, which include semipelite, psammite, arkosic metasandstone, quartzite, calcsilicate rocks and calcareous greywacke; and 2) younger, Paleoproterozoic granitic intrusions and pegmatite. No examples of potential Archean basement rocks were observed in the map area.

The tentative field results from this year's mapping in the Kasmere and Putahow lakes areas, when compared with the 2005 mapping results from the Nejanilini Lake area, suggest no significant differences in the nature and composition of the metasedimentary successions in the two areas. This may indicate that Paleoproterozoic metasedimentary rocks previously assigned to the Wollaston (Kasmere and Putahow lakes) and the Hurwitz (Nejanilini Lake) supergroups formed contemporaneously and in a similar or related tectonic setting in northern Manitoba.

Several occurrences of sulphide mineralization in bedrock and boulders were sampled and submitted for geochemical analysis. Uranium (pitchblende) was observed in outcrop and boulders, with the latter likely to be of local provenance, as described in the accompanying report on the surficial geology of the Kasmere–Putahow lakes area (Matile, GS-14, this volume).

Introduction

This report summarizes field observations and data collected during four weeks of 1:50 000 scale bedrock and surficial (Matile, GS-14, this volume) geological mapping at Kasmere and Putahow lakes during July and August 2006. The area was last mapped in the 1970s by the Manitoba Geological Survey; the results of this work are described by Weber et al. (1975a) and presented on the Kasmere Lake 1:250 000 scale bedrock compilation map (Manitoba Industry, Trade and Mines, 2000). Kasmere Lake is located approximately 40 km southeast of the Nunavut-Saskatchewan-Manitoba junction (Figure GS-13-1), and Putahow Lake straddles the Nunavut-Manitoba border and lies approximately 75 km east of the Saskatchewan-Manitoba border (NTS 64N). The area was accessed by float-equipped aircraft from Thompson via Treeline Lodge at Nueltin Lake. Bedrock exposure is generally poor throughout the map area and the extensive cover of glacial sediments is described in Matile (GS-14, this volume). The preliminary maps (Böhm and Anderson, 2006; Anderson and Böhm, 2006) include interpretation of the subsurface bedrock geology based on both the previous and new bedrock mapping, as well as aeromagnetic maps.

The 2006 field studies included detailed petrographic-petrological and structural mapping of the rare bedrock exposures, combined with mapping and description of the surficial geology. A large number of representative bedrock samples was collected for thin section, geochemical, isotopic and geochronological analysis. In addition, 21 till samples for kimberlite and base-metal indicator analysis were taken at an approximate spacing of 3 to 5 km within the bedrock mapping area (Matile, GS-14, this volume).

Bedrock and surficial mapping in the Kasmere and Putahow lakes areas was carried out to support mineral exploration activities in the region and to advance and update the currently limited understanding of the geology of a large part of Manitoba's far northwest. The 2006 field component forms part of an ongoing Manitoba Geological Survey (MGS) initiative to study the southeastern margin of the Archean Hearne craton in Manitoba's far north. The purpose is to further the understanding of the nature, evolution and mineral potential of the principal geological building blocks of Manitoba's far north. The MGS far north initiative commenced in 2004 with a Sm-Nd isotopic study carried out on archival samples from throughout the Nejanilini Domain (Böhm et al., 2004). This study was followed up in 2005 with targeted bedrock and surficial mapping and sampling in the Nejanilini Lake area (Anderson and Böhm, 2005; Anderson et al., 2005; Matile, 2005). From a bedrock geological perspective, these two studies provide detailed insight into the granulite-grade supracrustal and plutonic

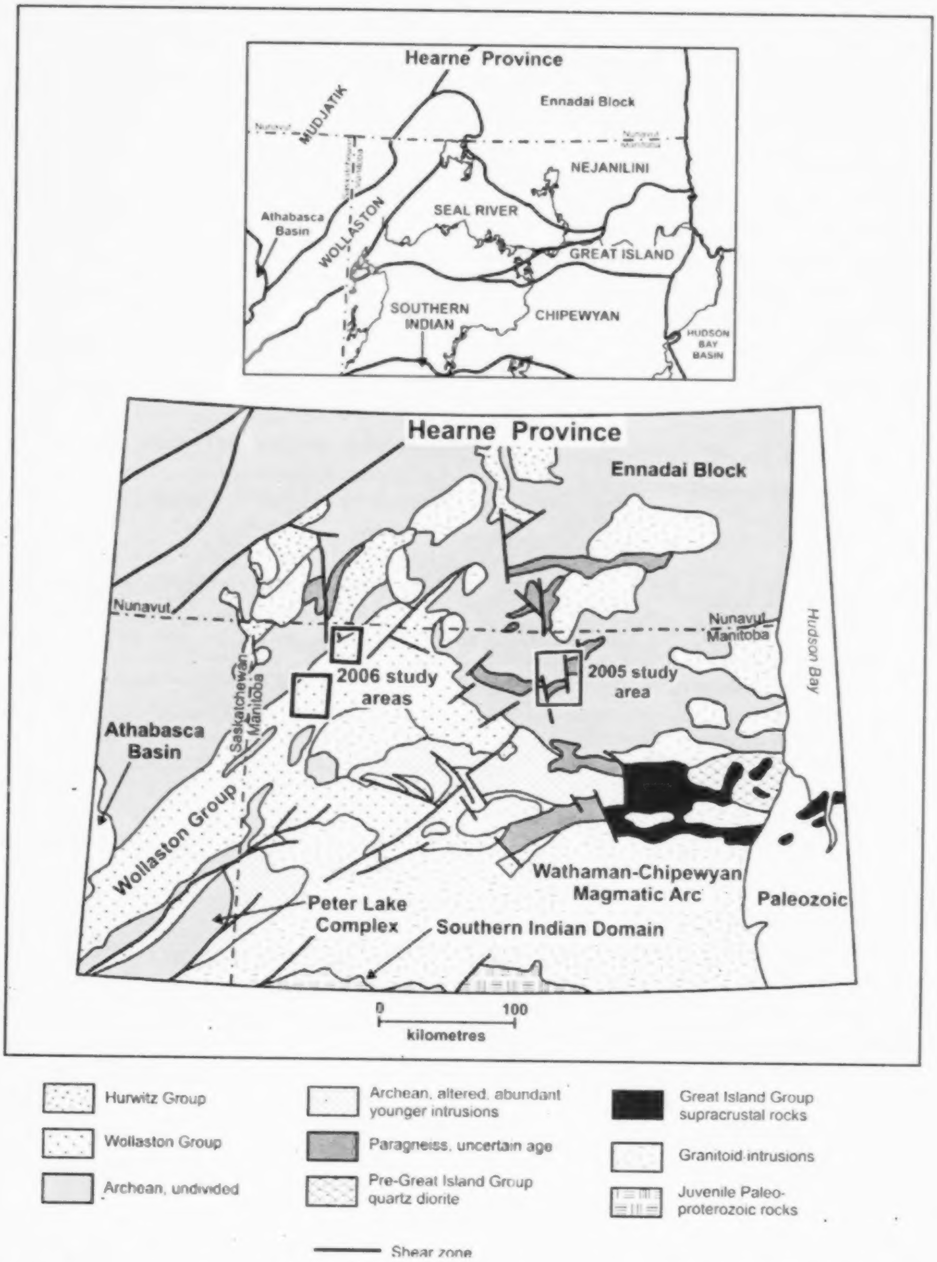
Hearne Province
Ennadai Block
MUDJATIK
Nunavut
Manitoba
NEJANILINI
Athabasca Basin
WOLLASTON
SEAL RIVER
GREAT ISLAND
SOUTHERN INDIAN
CHIPEWYAN
HUDSON BAY BASIN
Hearne Province
Ennadai Block
Nunavut
Nunavut
Manitoba
Hudson Bay
2006 study areas
2005 study area
Saskatchewan
Manitoba
Athabasca Basin
Wollaston Group
Wathaman-Chipewyan Magmatic Arc
Paleozoic
Peter Lake Complex
Southern Indian Domain
0
100
kilometres
Hurwitz Group
Wollaston Group
Archean, undivided
Archean, altered, abundant younger intrusions
Paragneiss, uncertain age
Pre-Great Island Group quartz diorite
Great Island Group supracrustal rocks
Granitoid intrusions
Juvenile Paleoproterozoic rocks
Shear zone

Figure GS-13-1: *Lithotectonic elements of the Trans-Hudson Orogen–Rae-Hearne craton region (modified after Manitoba Industry, Trade and Mines, 2000), with the 2006 mapping areas at Kasmere and Putahow lakes and the 2005 mapping area at Nejanilini Lake outlined.*

rocks of the Nejanilini Domain, including metasedimentary rocks tentatively assigned to the Hurwitz Group (Anderson et al., 2005). Accordingly, the 2006 field work was focussed west of the Nejanilini Domain, in the dominantly metasedimentary rocks that form part of the Paleoproterozoic Wollaston Domain. These rocks are best exposed in Manitoba along the Snyder–Kasmere–Tice–Putahow lakes corridor. For a regional synthesis, the results from the Kasmere and Putahow lakes project will be compared with those from the Nejanilini Lake project, as well as with extensive recent bedrock geological investigations in northeastern Saskatchewan (e.g., Harper et al., 2005a, b; Harper and Slimmon, 2005).

Geological setting

The Kasmere and Putahow lakes map areas form part of the southeastern flank of the Hearne craton in Manitoba. The Archean continental crust of the Hearne craton is overlain by Paleoproterozoic cover rocks and, together with the cover rocks, has undergone varying degrees of thermotectonism during the Paleoproterozoic Trans-Hudson orogeny (Cree Lake Ensialic Mobile Zone; Lewry et al., 1978; Lewry and Sibbald, 1980). The ensialic mobile zone has been subdivided into six domains in Saskatchewan and Manitoba: the Mudjatik, Peter Lake, Wollaston, Seal River, Great Island and Nejanilini domains (Figure GS-13-1). The domains are distinguished by their cover rocks, the proportion or absence of basement rocks, and their dominant structural trends. The Kasmere and Putahow lakes areas, investigated during the summer 2006 mapping, lies mainly within the Wollaston Domain and straddles the adjacent Mudjatik Domain to the northwest (Figure GS-13-1). The eastern boundary of the Mudjatik Domain is defined by a pronounced geophysical lineament that is traceable from the Manitoba-Saskatchewan border northeastward to the Nunavut border. A trough of low magnetic intensity, correlating with rocks of the Wollaston Domain, lies to the southeast of the more magnetic rock types in the Mudjatik Domain. This boundary is considered to be structural in origin and is likely similar in age to the Needle Falls Shear Zone (1855–1800 Ma; Stauffer and Lewry, 1993) that forms the eastern boundary of the Wollaston Domain in Saskatchewan.

No examples of potential Archean basement rocks to the Wollaston Domain metasedimentary rocks were observed in the map areas. Hence, the geology of the map areas is interpreted to consist predominantly of Paleoproterozoic (ca. 2.1–1.9 Ga; Kays, 1972; Weber et al., 1975b; Ray and Wanless, 1980; Ansdell et al., 2000; Yeo et al., 2000; Tran, 2001; Tran et al., 2003; Harper et al., 2005a, b) metasedimentary rocks of the Wollaston Supergroup, with subordinate granitic intrusive rocks probably related to magmatism during the Trans-Hudson orogeny. The Wollaston Supergroup supracrustal rocks appear to occupy elongate dome-and-basin structures, whereas the granitic intrusions tend to abruptly truncate the sedimentary rocks and locally contain large xenolithic rafts of the adjacent country rock. The Wollaston Supergroup is partially time-equivalent to Hurwitz Group metasedimentary rocks (ca. 2.4–1.9 Ga; Patterson and Heaman, 1991; Heaman and LeCheminant, 1993; Davis et al., 2000), the nearest exposures of which are in the Nejanilini Lake area in northern Manitoba (Anderson et al., 2005), in the Misaw Lake area in northwesternmost Saskatchewan (e.g., Harper et al., 2003; Harper and Slimmon, 2005), and in various parts of the Hearne craton in southern Nunavut and the Northwest Territories.

The Wollaston Supergroup in Saskatchewan has been subdivided into three major sequences (Harper et al., 2005a, b; Yeo and Delaney, in press). Exposures of the Wollaston Supergroup in the Kasmere and Putahow lakes areas are comparatively scarce but tentatively interpreted to be most similar to the Middle Sequence, equivalent to the Daly Lake Group of Yeo and Delaney (in press) in Saskatchewan. The Middle Sequence in the Wollaston Lake area of Saskatchewan represents a foreland basin sequence that comprises, from base to top, psammite, pelite and graphitic pelite, along with various calcareous metasedimentary rocks (including marble), overlain by pelite and psammite, and topped by arkose and quartzite (Harper et al., 2005a, b). Detrital zircon populations in a number of Wollaston Supergroup metasedimentary rocks analyzed from the Wollaston Lake area indicate an Archean provenance (Annesley et al., 1992). Rubidium-strontium ages for semipelitic and pelitic rocks of the Wollaston Domain, which range from 1815 to 1835 Ma (Weber et al., 1975b; Cummings and Scott, 1976), are evidence for Paleoproterozoic metamorphism. The high initial $^{87}Sr/^{86}Sr$ ratios for these rocks suggest that a component of their sedimentary provenance was Archean; however, the ratio does not support an Archean age of sedimentation.

Biotite psammite gneiss of the Wollaston Supergroup in northeastern Saskatchewan and psammite and semipelite in the Kasmere Lake area are considered to be stratigraphic equivalents, based on their lithological similarity and apparent lateral gradation (Weber et al., 1975a). These formations can, in turn, likely be correlated with the Ameto Formation of the Hurwitz Group in Nunavut. Zircon and baddeleyite from gabbro sills in the lower to middle Ameto Formation, in the area of North Henik Lake, Nunavut, were dated by the U-Pb method at 2094 +26/–17 Ma (Patterson and Heaman, 1991). This establishes a minimum depositional age of ca. 2.10 Ga for the lower to middle Ameto Formation of the Hurwitz Group.

A similar minimum age of ca. 2.10 Ga has been established for the Wollaston Group in Saskatchewan. A date of 2076 ±3 Ma, interpreted to be an igneous crystallization age, was obtained from samples of mylonitic quartzofeldspathic gneiss in the rocks of the Courtenay Lake Formation of the Wollaston Group (Annesley et al., 1992). Courtenay Lake Formation conglomerate, arkose and quartzite are interlayered with mafic volcanic rocks characterized by within-plate lithogeochemistry, thus favouring emplacement in a continental rift setting (Fossenier et al., 1995; MacNeil et al., 1997). The timing of continental rifting recorded in the Courtenay Lake Formation in Saskatchewan, at ca. 2100 Ma, is consistent with the observations in Nunavut and Manitoba.

Rocks of the Wollaston Supergroup were intruded by granitic and leucogranitic bodies, along with pegmatite. Granitic and granitic pegmatite rocks in the Wollaston Domain in Saskatchewan yield ages ranging from 1.80

to 1.84 Ga (Annesley et al., 1992, 1997), which corresponds to the main period of Hudson granite emplacement throughout the western Churchill Province (Peterson et al., 2000, 2002). The granitic rocks within the Wollaston Supergroup metasedimentary rocks in the Kasmere and Putahow lakes areas are generally nonmagnetic and thus produce no anomalies within the areas of generally low magnetic intensity that correspond to the metasedimentary bedrock (Anderson and Böhm, 2006; Böhm and Anderson, 2006). A distinctive northwest-trending magnetic lineament, which is most prominent southeast of Kasmere Lake (Figure GS-13-2; Böhm and Anderson, 2006), is interpreted to represent an unexposed, ca. 1.27 Ga, Mackenzie diabase dike (LeCheminant and Heaman, 1989).

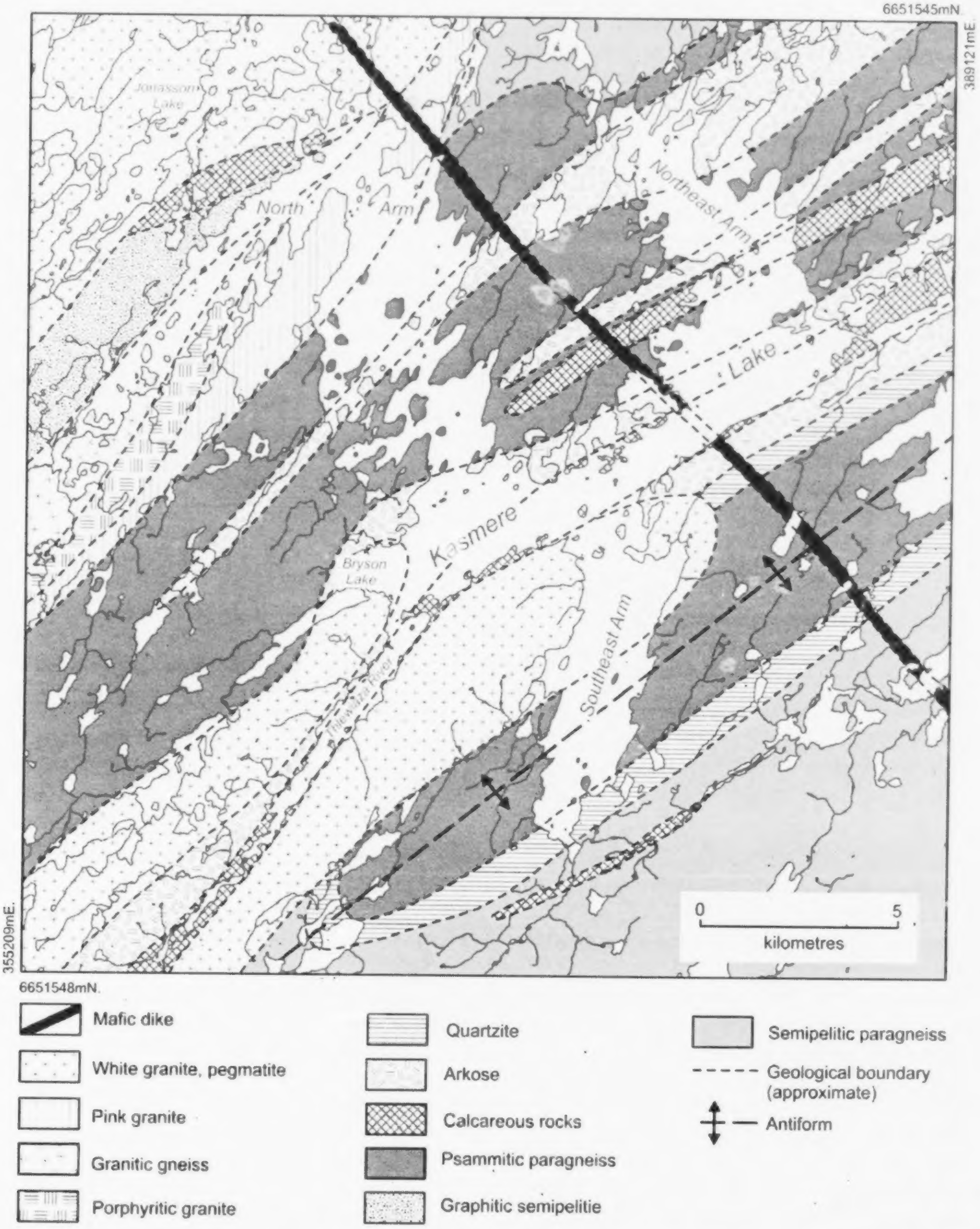
6651545mN
389121mE
Jonasson Lake
North
Arm
Northeast Arm
Lake
Kasmere
Bryson Lake
Southeast Arm
Thlewiaza River
0
5
kilometres
355209mE
6651548mN
Mafic dike
White granite, pegmatite
Pink granite
Granitic gneiss
Porphyritic granite
Quartzite
Arkose
Calcareous rocks
Psammitic paragneiss
Graphitic semipelitie
Semipelitic paragneiss
Geological boundary (approximate)
Antiform

Figure GS-13-2: *Simplified, interpretative bedrock geology of the Kasmere Lake area, based on scarce bedrock exposures and detailed magnetic data.*

Bedrock geology of the Kasmere and Putahow lakes areas

The interpretive bedrock geology of the Kasmere and Putahow lakes map areas is summarized in Figures GS-13-2 and -3, respectively, and integrated in the regional geology on the 1:50 000 scale preliminary geological maps PMAP2006-4 (Böhm and Anderson, 2006) and PMAP2006-5 (Anderson and Böhm, 2006), respectively. Due to extensive glacial drift cover (Matile, GS-14, this volume), bedrock exposures at Kasmere and Putahow lakes are limited. The northeast-trending Quaternary landforms are subparallel to the dominantly northeast trends of the bedrock geology at Kasmere and Putahow lakes (Figures GS-13-2 and -3), which makes identification of potential bedrock exposures on airphotos difficult. The scarce, largely lichen-covered bedrock exposures occur mainly along lake shorelines and are typically frost heaved. Block and boulder fields (felsenmeer) proved useful in many areas to constrain the possible bedrock geology.

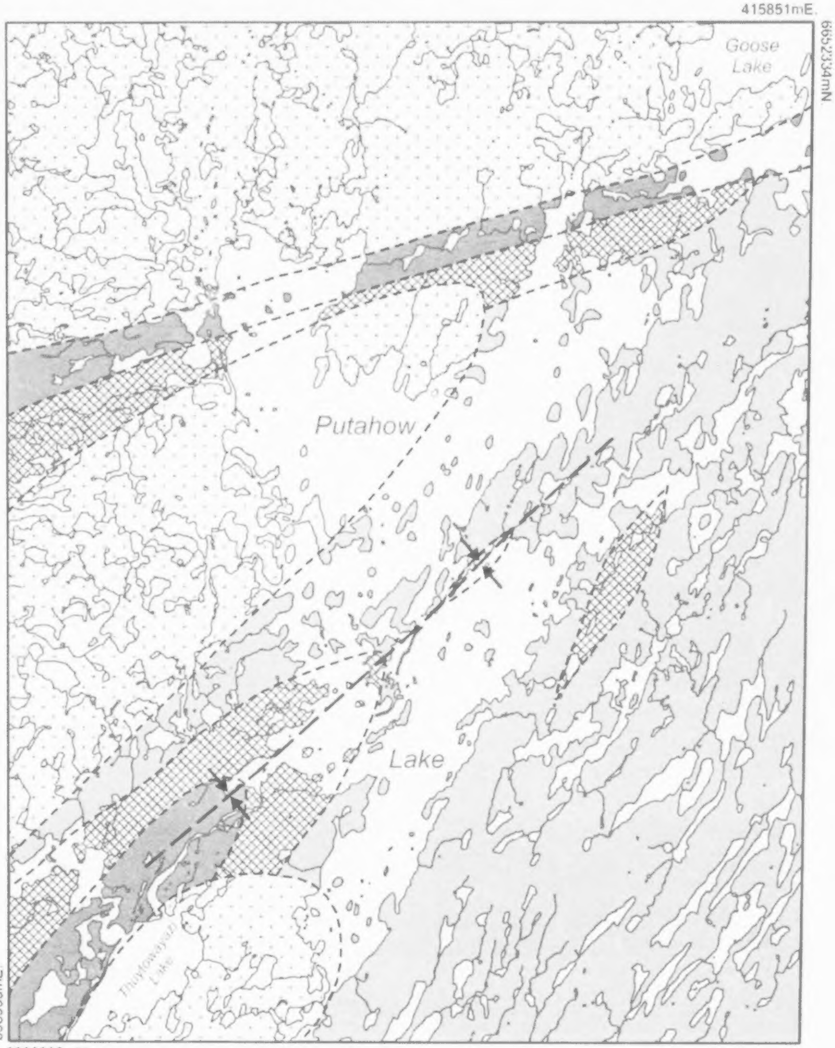
415851mE.
6652334mN
Goose Lake
Putahow
Lake
Thuytowayasi Lake
398993mE.
6630902mN.
0
5
kilometres
White granite, pegmatite, local granitic gneiss
Calcareous rocks
Psammitic paragneiss
Semipelitic paragneiss
Geological boundary (approximate)
Synform

Figure GS-13-3: Simplified, interpretive bedrock geology of the Putahow Lake area, based on scarce bedrock exposures and magnetic data.

As described below and illustrated in Figures GS-13-2 to -4, bedrock exposures at Kasmere and Putahow lakes can be grouped into two main mappable units: 1) presumably Paleoproterozoic metasedimentary rocks of the Wollaston Supergroup; and 2) younger, presumably Trans-Hudson–related Paleoproterozoic granitic intrusions and pegmatite. No rocks potentially older than the Wollaston Supergroup metasedimentary rocks were observed in the Kasmere and Putahow lakes map areas. High-grade metamorphism, concurrent with deformation, is indicated by synkinematic garnet-cordierite-sillimanite porphyroblasts and leucosome veins in the metasedimentary rocks of the Wollaston Supergroup (e.g., Figure GS-13-4a). They indicate relatively low-pressure, high-temperature regional metamorphism, corresponding to middle to upper amphibolite facies conditions. Structurally, these rocks show evidence for polyphase deformation, with at least two generations of foliation and folds. The main phase of felsic intrusions appears to be syn- to postdeformational, based on both crosscutting and layer-parallel granitic injection and generally weak foliation in the felsic intrusive rocks (e.g., Figure GS-13-4b).

Metasedimentary rocks of the Wollaston Domain

The Wollaston Domain in the study area has a dominant northeasterly trend and is approximately 35 km wide at the south end of Kasmere Lake. Northeast of Kasmere Lake, the domain is less well defined and narrows to approximately 20 km at Putahow Lake. In the study area, the Wollaston Domain appears to form elongate structural domes, resulting from doubly plunging antiformal and synformal folds. At the Southeast Arm of Kasmere Lake, parasitic folds in paragneiss and regional aeromagnetic trends indicate an antiformal dome structure cored by psammitic and semipelitic gneiss and rimmed by quartzite and locally by arkose (Figure GS-13-2). In the paragneiss, a moderately southwest-plunging synform is traceable for several kilometres across central Putahow Lake, and contains pegmatite intrusions along its hinge line (Figure GS-13-3).

The basal unit of the Wollaston Group in Saskatchewan is a psammitic to semipelitic garnet-biotite±cordierite gneiss. In the Kasmere and Putahow lakes areas, garnet-biotite semipelitic gneiss appears to contain, and/or be overlain by, a compositionally variable sequence of calcsilicate rocks that may represent calcareous sedimentary rocks deposited in a platform setting (Weber et al., 1975a). The calcsilicate rocks appear to be overlain by regionally discontinuous psammitic gneiss and locally by quartzite and arkosic rocks. This metasedimentary succession may signify a tectonic change from a platform setting to possible uplift. Alternatively, the quartzite and arkosic rocks may define an antiformal culmination, and would thus be overlain by the calcsilicate rocks, which occur outside the quartzite at southeastern Kasmere Lake. The latter structural and resultant stratigraphic interpretation is more consistent with a classic basin subsidence.

Quartzite, semipelite and psammite samples from the Kasmere Lake and Putahow–Goose lakes areas have been submitted for U-Pb zircon age dating and Nd isotope analysis. Results from these analyses will permit a more scientifically rigorous comparison of the metasedimentary rocks at Kasmere and Putahow lakes with those of the Wollaston Supergroup rocks in Saskatchewan, and possibly related metasedimentary rocks previously assigned to the Hurwitz Group at Nejanilini Lake.

Semipelitic paragneiss

Semipelitic paragneiss, interpreted as metagreywacke, generally shows a well-developed metamorphic layering defined by alternating grey to dark grey, biotite-rich layers (1–100 cm thick), and white to beige, medium- to coarse-grained felsic lits (e.g., Figure GS-13-4c). At northwestern Kasmere Lake, strongly graphitic biotite-rich semipelite is beige to rusty brown to grey, commonly coarse grained, well foliated to cataclastic, and schistose to gneissic (Figure GS-13-2; Figure GS-13-4d).

Semipelitic paragneiss is characteristically biotite rich and graphitic, and contains quartz-plagioclase ±garnet ±cordierite ±sillimanite (faserkiesel; e.g., Figure GS-13-4e), as well as white tonalitic leucosome or partial melt veins (e.g., Figure GS-13-4a) and granitic pegmatite dikes. Semipelitic gneiss is commonly interlayered with calcareous psammite or semipelite and/or centimetre- to metre-thick layers of psammitic gneiss (Figure GS-13-4e). Areas underlain by these rocks generally coincide with areas of low magnetic intensity (2000–2200 gammas), such as large parts of the southeastern Kasmere and Putahow lakes areas (Böhm and Anderson, 2006; Anderson and Böhm, 2006).

Psammitic paragneiss

Psammitic paragneiss, interpreted to be derived from quartz-rich greywacke, is generally more quartz±feldspar rich compared to the above semipelitic paragneiss, with which it is closely associated and locally interlayered. Together they form the predominant rock types in the Kasmere and Putahow lakes map areas (Figures GS-13-2 and -3). The psammite is dark grey to light grey, fine to coarse grained, well foliated and layered, schistose to gneissic, and locally contains pebbly layers defined by larger quartz and/or feldspar aggregates. Psammitic rocks commonly contain K-feldspar, quartz, plagioclase, biotite ±sillimanite/cordierite (faserkiesel) ±garnet ±hornblende, as well as abundant white to pink leucosome with some coarse-grained blue cordierite and rare garnet. The best exposures of psammitic rocks are at southwestern Bryson

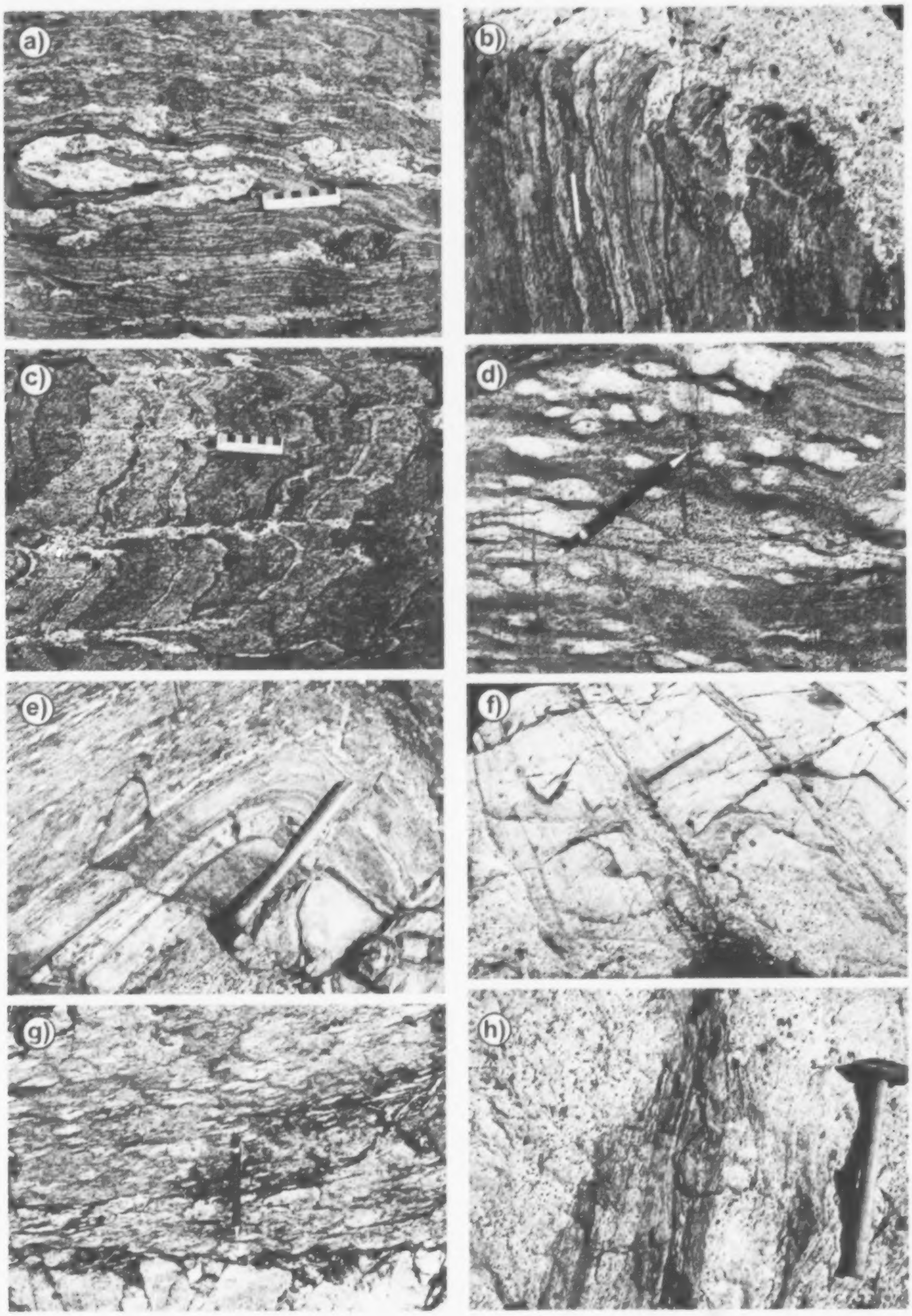

Figure GS-13-4: *Characteristic bedrock exposures at Kasmere and Putahow lakes:* ***a)*** *Folded and sheared garnet-quartz-rich melt vein in semipelite south of the Southeast Arm of Kasmere Lake.* ***b)*** *Strongly foliated and layered quartz-porphyroblastic (faserkiesel) garnet-biotite semipelitic paragneiss cut by leucogranite, south shore of Goose Lake, northeast of Putahow Lake (note layer-parallel and crosscutting aspect of the intrusion).* ***c)*** *Folded garnet-biotite-rich semipelite with minor psammitic and calcareous interlayers south of the Southeast Arm of Kasmere Lake.* ***d)*** *Psammitic to semipelitic gneiss with quartzofeldspathic nodules and feldspar porphyroblasts from Bryson Lake, southwest of Kasmere Lake.* ***e)*** *Strongly foliated and folded, layered semipelitic paragneiss, Southwest Arm of Kasmere Lake (Thlewiaza River).* ***f)*** *Bedded quartzite with sillimanite-porphyroblastic semipelitic interlayers from southeast Kasmere Lake.* ***g)*** *Arkose containing up to 40% fibrous quartz-sillimanite (faserkiesel) nodules from southeast Kasmere Lake.* ***h)*** *Semipelitic paragneiss screen in leucocratic granitic pegmatite, southwest of Kasmere Lake (Thlewiaza River).*

Lake, at west-central Kasmere Lake (Figure GS-13-2) and in the northern Putahow Lake to southern Goose Lake area (Figure GS-13-3).

Calcareous rocks

Calcareous rocks range in composition from pure carbonate (marble) to calcsilicate to calcareous psammite and semipelite. These rocks are characteristically white to pale green to pale grey-green, well foliated and layered or laminated, and vary, depending on composition and grade of deformation, from fine to coarse grained and schistose to gneissic. Recessive weathering and erosion of calcareous layers within mixed silicate-calcsilicate rocks accentuates the gneissic layering in these rocks, which is typically highly contorted due to intense multiphase folding. Marble locally includes interlayers of pelitic and psammitic gneiss. The mineral assemblage typically consists of plagioclase, quartz and biotite, with variable amounts of carbonate, diopside, K-feldspar and hornblende. Marble comprises calcite, dolomite ±diopside ±biotite, whereas calcareous arkose contains alternating pink K-feldspar– and green calcsilicate–rich layers (diopside ±biotite ±actinolite). Calcic psammitic and pelitic wacke contain quartz, feldspar, biotite ±diopside ±amphibole ±carbonate.

Good exposures of marble and calcsilicate rocks occur at the base of Kasmere Falls and downstream along the Thlewiaza River, whereas intensely layered, folded and/or lineated calcsilicate gneiss occur at the east end of Kasmere Lake in large block fields. Calcareous units are relatively less competent to weathering and thus are rarely exposed unless interlayered with other metasedimentary rocks.

Quartzite and arkose

Exposures of quartzite were mapped at southeastern Kasmere Lake and are interpreted, mainly based on magnetic data, to form the steep flanks of an antiformal dome structure (Figure GS-13-2). In this area, the quartzite exposures closely correspond to linear magnetic highs (Böhm and Anderson, 2006).

Quartzite is white, beige, light grey to greenish pink, generally well layered/bedded and foliated, and fine to coarse grained. It contains quartz, K-feldspar, plagioclase, biotite ±garnet ±hornblende ±pyrite ±magnetite, and locally contains sillimanite (faserkiesel) in semipelitic interlayers up to 20 cm thick (Figure GS-13-4f). At southeastern Kasmere Lake, quartzite is in contact and locally interlayered with pink and light grey arkose, which is weakly to well layered and contains up to 40% light grey faserkiesel nodules (Figure GS-13-4g).

Felsic intrusive rocks

Interpreted Paleoproterozoic intrusive rocks at Kasmere and Putahow lakes include foliated to porphyritic granite, abundant leucocratic, weakly deformed potassic granitic rocks, and possibly related potassic granitic pegmatite. Larger granite bodies extend for several kilometres, whereas many smaller irregular bodies and pegmatite dikes are too small to be represented on the maps. These felsic intrusive rocks presumably belong to the Hudson and/or Nueltin suites of granite (ca. 1.86–1.75 Ga; e.g., Peterson et al., 2000). Except for larger granite bodies in the northwestern Kasmere Lake area, the felsic intrusions are not notably magnetic and therefore don't produce a magnetic contrast within the metasedimentary rocks. White potassic granite and pegmatite are the dominant felsic intrusive rocks at southwestern Kasmere Lake, whereas granitic intrusions at northwestern Kasmere Lake can be subdivided into relatively weakly deformed pink and white granites, well-foliated porphyritic granite and granite gneiss (Figure GS-13-2). West and north of Putahow Lake (Figure GS-13-3), felsic intrusive bodies are dominantly a white to beige granite and granodiorite that is commonly garnet and tourmaline bearing near the contact with paragneiss. Uranium-lead dating and Nd isotope analysis on the dominant leucogranite phase at Kasmere and Putahow lakes are planned.

Granitic gneiss

Based on their strong fabric development, the medium- to coarse-grained to porphyritic, locally augen-textured, moderately to strongly foliated granitic gneiss in the west part of the Northwest Arm of Kasmere Lake may be the oldest exposed phase of granitic rocks in the map areas (Figure GS-13-2). The granitic gneiss is white to light grey, moderately layered and/or veined by granitic pegmatite, and contains xenoliths of paragneiss. Main minerals of the granitic gneiss are quartz, K-feldspar, plagioclase, biotite ±muscovite ±magnetite.

Porphyritic granite seems to form a distinct intrusive body within less foliated granite at northwestern Kasmere Lake (Figure GS-13-2). The large granitic intrusion at west-central Putahow Lake (Figure GS-13-3) is composed of fine- to medium-grained, moderately foliated granodiorite to granite and contains patches and schlieren of the white leucogranite described below.

Granitic rocks including leucogranite, syenogranite

White leucocratic granite forms the main intrusive rocks in the map area. Good examples are the granite bodies, several kilometres in size, at southwestern and northwestern Kasmere Lake. In detail, these intrusions are dominantly subconcordant sheets or sills in the paragneiss. The granite is commonly medium to coarse grained to locally pegmatitic, weakly foliated and layered, and locally xenolithic and/or gneissic (e.g., Figure GS-13-4h). Main mineral constituents are K-feldspar, quartz, plagioclase, biotite ±muscovite. A pink variety of potassic granite is exposed at northwestern Kasmere Lake and may be related to the white granite (Figure GS-13-2). The white granite intrusion at the southwest end of Putahow Lake (Figure GS-13-3) is potassic and locally contains up to several percent tourmaline and/or garnet.

Granitic pegmatite

Veins, dikes and irregular pegmatite bodies commonly form diffuse patches and dikes in granitic rocks and are rarely of mappable size. Pegmatite is white to pinkish beige, massive to moderately layered and weakly foliated. Main minerals are K-feldspar, quartz, plagioclase ±biotite ±muscovite ±garnet ±tourmaline, where the accessory mineral assemblage of the pegmatite appears to be governed by the composition of the rocks they intrude. In many cases, pegmatite seems to be closely associated with the above granitic rocks. Some larger pegmatite intrusions appear to be axial planar to a main fold structure or occur along the transposed to sheared fold limbs.

Economic considerations

The northeastern extension of the Wollaston Domain into the Kasmere Lake study area was the focus of considerable exploration in the 1960s and 1970s by a number of companies, as well as comprehensive geophysical and geochemical surveys completed by government agencies. The Uranium Reconnaissance Program (URP) was a nation-wide survey carried out by the Geological Survey of Canada, with Manitoba participating in 1975 and 1976. The survey was flown on a line spacing of 5 km, using a high-sensitivity gamma-ray spectrometer. Lake-centre sediment sampling, with an approximate density of one sample per 13 km^2, was carried out as part of a concurrent geochemical survey. The URP was intended to define broad regions containing higher than average U contents. Broad zones of U enrichment were delineated in northern Manitoba, mainly in the Kasmere Lake map area.

The potential for uranium deposits in this area was originally indicated from limited prospecting, followed by more extensive exploration, by Denison Mines Ltd., Dynamic Petroleum Ltd. and Yukon Antimony Corp. Ltd. (Weber et al., 1975a). Between Snyder Lake and Kasmere Lake, the survey revealed a chain of lake sediment anomalies, trains of radiometric anomalies and relatively higher ratios of U to Th. The URP survey also indicated a complex U-Ni-Co lake sediment geochemical anomaly restricted to the region extending from Snyder Lake to Fort Hall and Thanout lakes. The anomalies can be related to calcsilicate rocks that contain a larger than average component of amphibolite and uniquely contain Co- and Ni-bearing minerals and trace amounts of Au. Subsequent to the release of the URP survey, extensive ground follow-up was carried out by mining companies, such as United Siscoe Mines Ltd. in 1976-1980 (Assessment File 93481, Manitoba Science, Technology, Energy and Mines, Winnipeg) and Zelon Enterprises Ltd. in 1982 (A.F. 93489), as well as by the Manitoba Geological Survey and the Geological Survey of Canada. This activity is summarized in Schledewitz (1986) and Soonawala (1980).

Active exploration for U and Au in northwestern Manitoba is being conducted by CanAlaska Ventures Ltd. (2006) in the Snyder–Kasmere lakes area and by Santoy Resources Ltd. (2006) in the Kasmere Lake area, where U, Mo, Co, Ni, Cu and Au mineralization have been located mainly in boulders and some outcrops. The source of the high-grade boulders, however, has not been sufficiently located by the historical exploration activity and is partly the focus of the current surficial geological studies (Matile, GS-14, this volume). On a regional scale, U mineralization occurs as unconformity-type, basement-hosted U in both calcsilicate rocks and garnet-biotite semipelitic paragneiss of the Wollaston Group. In addition, U occurs in the leucocratic granitic rocks and pegmatite in the metasedimentary rocks.

The metasedimentary rocks at Kasmere and Putahow lakes are tentatively interpreted to represent a platform cover sequence, which was likely deposited on top of the Archean Hearne craton along the passive, southeastern craton margin. Platform cover sequences typically form in response to continental extension, which may include the development of rift basins. In many cover sequences, high heat flow and magmatism associated with rifting have produced significant hydrothermal and magmatic ore deposits. Similar potential may exist in the Wollaston Supergroup metasedimentary rocks in the Kasmere and Putahow lakes areas. Known base-metal occurrences occur mainly in the calcsilicate rocks. A sedimentary origin is the preferred interpretation for the base-metal occurrences (Weber et al., 1975a). The rocks of the Courtenay Lake–Cairns Lake fold belt, which lie along the eastern edge of the Wollaston Group in Saskatchewan, also contain a number of base-metal occurrences interpreted to fit a sedimentary exhalitive origin (Delaney et al., 1997).

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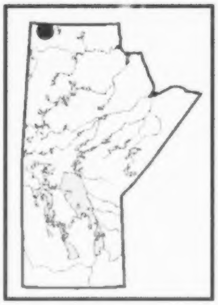
GS-14 Surficial geological investigations in the Kasmere–Putahow lakes area, northwestern Manitoba (parts of NTS 64N10, 11, 14 and 15)

by G.L.D. Matile



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Summary

An understanding of ice-flow history has long been an important aspect of mineral exploration in glaciated terrains. After two field-mapping programs in Manitoba's far north working closely with Precambrian bedrock geologists, it has become clear that understanding subglacial meltwater erosion is equally important in determining bedrock sources for sediment samples and potential ore-bearing surface and near-surface boulders. This conclusion is in agreement with work done by Quaternary geologists in similar glacial settings in nearby Phelps Lake area in northeastern Saskatchewan and the Lac de Gras area of the Northwest Territories.

Although, in the Kasmere–Putahow lakes area, the orientation of narrow cigar-shaped drumlins closely mimics the southerly ice-flow direction as determined by glacial striations, many other landforms in the area such as broader cresentic drumlins, Rogen moraines, tunnel channels and eskers can be highly variable in orientation. These landforms are believed to be derived from either erosional or depositional processes associated with turbulent subglacial meltwater flow.

This summer's mapping program included the collection of 21 diamict samples, each 20 kg in weight, from the shores of Kasmere and Putahow lakes with a sample spacing of approximately 5 km. Subtle variations in sediment sorting, or the lack thereof, within the matrix of these samples, is key to understanding the depositional environments and genesis of the landforms from which they were derived.

Introduction

Surficial mapping and glacial sediment sampling was carried out in conjunction with Precambrian bedrock mapping (Böhm and Anderson, GS-13, this volume) in the Kasmere–Putahow lakes area in support of mineral exploration. Kasmere Lake is located approximately 50 km east of the Saskatchewan border and 40 km south of Nunavut, and Putahow Lake, 40 km to the northeast, is within 5 km of the Nunavut border (Figure GS-14-1). Local relief tends to be around 10 to 15 m. The larger eskers are 30 m high. The largest ridges are up to 80 m high and are possibly, at least in part, cored with durable bedrock. Precambrian bedrock outcrop is sparse and typically badly weathered and consists of metasedimentary rocks of the Wollaston Domain and younger granitic intrusions (Böhm and Anderson, GS-13, this volume).

Both lakes are situated south of the treeline in an area of discontinuous permafrost. Permafrost and winter lake ice features, although present, are far less dramatic than in the Nejanilini Lake area, 180 km to the east (Figure GS-14-1), which was mapped in 2005 (Anderson et al., 2005). Common to Nejanilini Lake are well developed

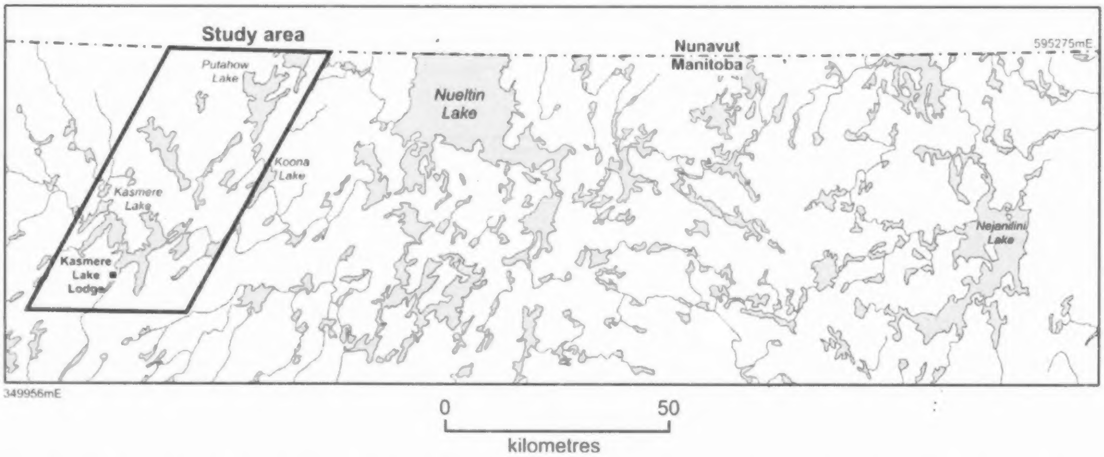

***Figure GS-14-1:** Location map of the Kasmere–Putahow lakes surficial map area (Matile, 2006) and Nejanilini Lake to the east.*

'fortress islands', shorelines with boulders pushed landward and concentrated on the lakeshore by thermally expanded and contracted winter lake ice. On Kasmere and Putahow lakes these 'islands' were uncommon and restricted to short stretches of shoreline up to 100 m in length. Permafrost and permafrost features such as patterned ground, common in the Nejanilini area, were only observed in one location during this year's mapping. Felsenmeer, fields of frost-shattered bedrock, were frequently observed and helpful to bedrock mapping in the absence of local bedrock outcrop.

The area is situated within the Keewatin Sector of the Laurentide ice sheet. Glacial ice flowed southward over Precambrian rocks producing a glacial diamict with a very sandy matrix. Glacial diamict is the prominent surface material, followed by organic wetlands and glaciofluvial sediments (eskers and esker complexes). As was the case in the Nejanilini Lake area, glacially derived boulders litter the landscape. Bedrock outcrops are typically badly weathered and as a result there were very few measurable glacial striations and no readily identifiable water-sculpted bedrock forms observed during field mapping. Major south-southwest–trending eskers occur approximately every 20 km laterally with numerous smaller tributary eskers in between. The area was previously sampled and mapped in the late 1970s at a scale of 1:250 000 by Dredge et al. (1982) and later released as a 1:500 000 scale map compilation for northwestern Manitoba by Dredge et al. (1986). Campbell (2002) mapped the Keseechewun Lake area in nearby northeastern Saskatchewan and concluded that "subglacial meltwater erosion played a major role in the formation of the present-day landscape". Rampton (2000) also describes an array of erosional and depositional landforms in southeastern Northwest Territories, which he attributes to broad subglacial meltwater flows. Horseshoe-shaped depressions, with the closed end pointing up-ice and commonly filled with water, are numerous and are strong evidence of the presence of turbulent subglacial meltwater.

Twenty-one glacial diamict samples were collected from hand-dug holes. No natural exposures were found in the diamict. The diamict sample sites were generally within 100 m of the lakeshore with a spacing of approximately 5 km. The samples were taken 10 to 20 cm below an abrupt decrease in soil oxidation; which was interpreted as the C horizon. Samples were taken within a 40 to 50 cm interval, at a depth ranging from 0.4 to 1.0 m depending on soil thickness and stone content. Pebbles in the 2 to 4 cm size range were collected separately and classified back at camp by the bedrock mappers based on the regional bedrock. The diamict samples will be processed for indicator minerals, gold grains and geochemistry.

Mineral occurrences

There are a number of mineral occurrences in the Kasmere–Putahow lakes area. In 1980, U-rich boulders were reported from the north end of Kasmere Lake (Assessment File 93481, Manitoba Science, Technology, Energy and Mines, Winnipeg). Detailed investigations were carried out in the area and 55 to 60 U-rich boulders were found. Some of these boulders were also Au-rich and the bedrock source was determined to be approximately 100 m from the location of the boulders (A.F. 93481). In 1981, U-Pb, Ni-Cu and Ni-Co showings were reported south of Kasmere Lake (Assessment File 93489, Manitoba Science, Technology, Energy and Mines, Winnipeg). In 2006, CanAlaska Ventures Ltd. reported mineralized boulders, south and west of Kasmere Lake, containing up to 11% U_3O_8 and 5% Mo and one bedrock outcrop sample containing 10% U_3O_8 (Dasler, 2006). Six diamict samples were taken by Dredge and Pehrsson (2006) in the Kasmere–Putahow lakes map area, but anomalous values were only recorded in the Putahow Lake area: Co, Cr, Cu, Fe, Mo, Ni, Zn, Pb, U to the west, Cr, Cu to the north and U to the south.

During field investigations for this project, a 40 m bedrock trench was encountered exposing uranium mineralization in leucogranite 400 m southwest of Kasmere Lake Lodge on Kasmere Lake. Also, a concentration of sulphide-rich arkosic boulders was discovered 2.5 km north of Kasmere Lake Lodge. The significance of this boulder concentration, other than its mineralization, is that it is a good example of how concentrated boulders of a single lithology can occur, and how rapidly boulder lithology can change, indicating an extremely short glacial transport distance. In this particular example, all the boulders in this concentration are the same lithology, and both the boulders and the fine sediments in between (the diamict matrix) are heavily oxidized. Also, a well defined line could be drawn diagonally down the west slope of the drumlin on which the boulders were found; with the mineralized boulders to the south of the line and granitic boulders to the north, which were an equally lithologically homogeneous boulder cluster.

Surficial geology

Peat-filled wetlands make up a small portion of the surface material in the Kasmere–Putahow lakes area. The peat is commonly more than 3 m thick and contains abundant charcoal layers. Glaciofluvial sand and gravel also makes up a small portion of the surface material. Unlike the Nejanilini Lake area where stratified sand essentially covered the entire area at depth (Anderson et al., 2005), stratified sand and gravel in this area appears to be restricted to esker corridors, which can be up to 2 km across. Major eskers up to 30 m high meander across the landscape trending south-southwest and tend to occur at a fairly regular interval of 20 km. Eskers generally have a central peaked ridge or in places multiple ridges (Figure GS-14-2) and were deposited in a pre-existing tunnel channel. Tributary eskers are arranged at acute angles to the major eskers and tend to be significantly smaller. The eskers are composed primarily of sand, particularly in the flanking fans, but can contain very coarse gravel including clast-supported, open-framework boulder gravel.

Due to the pristine nature of the landforms (e.g., peaked esker ridges) and other smaller surficial features (e.g., perched boulders) and the lack of lacustrine sediments, it is believed that there was no proglacial lake along the retreating glacial ice margin in this area. This was also true for the Nejanilini Lake area (Anderson et al., 2005) and, as a result, it is believed that glacial Lake Agassiz did not extend this far north in Manitoba.

Surface sediments are dominated by glacial diamict. The diamict is typically light grey in colour. The Munsell colour ranged from 5Y 7/2 to 2.5Y 5/3 (Munsell Color, 1975). It is generally uncompacted (loose) and homogeneous with a matrix texture of silty sand. The diamict was found to be noncalcareous even in areas where the local bedrock was strongly calcareous, supracrustal metasedimentary rocks. The stone content is highly variable and generally decreases downwards. At three of the diamict sample sites, the diamict matrix displayed some degree of sorting and was less silty than normal. The thickness of the diamict is unknown but hand-dug sample holes never penetrated the diamict. In contrast, in the Nejanilini Lake area, the typical stratigraphy comprised more than 5 m of stratified sand overlain by approximately 1 m of glacial diamict (Anderson et al., 2005). This diamict was less homogeneous than diamict from this year's map area and generally contained numerous sand seams.

The diamict surface is overwhelmingly streamlined in a south-southwest direction (Matile, 2006). There does appear to be some organization to the landforms. Individual landform types are typically found in clusters or commonly grouped in curvilinear corridors (Figure GS-14-3a), which are aligned subparallel to the drumlins and ice flow in the area. The landforms include spindle drumlins (Figure GS-14-3b), crescentic drumlins (Figure GS-14-3c), Rogen moraines (Figure GS-14-3d), tunnel channels (Figure GS-14-3e) and eskers (Figure GS-14-3f). The degree to which the surface in the area of these landforms has been eroded seems to increase from spindle drumlins (spindle-shaped landforms can be ridges or grooves), which tend to be found on smoother, elevated terrain, to tunnel channels, which tend to be a clean box-style channel with an increased probability of bedrock outcrop within the channel. In some situations there seems to be an interference pattern between landform types possibly leading to a more disorganized pattern such as hummocky terrain.

Local relief on the landforms tends to be around 10 m. However, Rogen moraines and eskers can be up to 30 m high. Rogen moraines are transverse landforms with a gentle northern slope and a steep southern slope. In several cases, meltwater corridors appear to be determining the shape of lakes suggesting that the land within the corridor has been deflated more than the surrounding area (Figure GS-14-4).

Boulders are virtually always found lying on or imbedded in the surface of the diamict. The boulders are surprisingly consistent lithologically in a particular location and the lithology changes rapidly from area to area, presumably mimicking the local bedrock. Similarly, in the Nejanilini Lake area, 2 to 4 cm pebble lithology from diamict samples and observations in boulder fields were found to be very similar to the local bedrock (Anderson et al., 2005). Pebble counts from the diamict samples in the Kasmere–Putahow lakes area also suggest a short transport distance. Dredge (1981) also concluded that the glacial transport distances were very short,

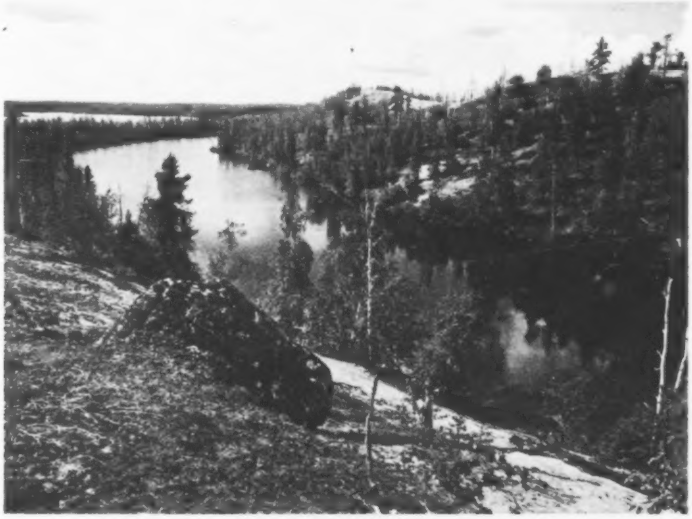

Figure GS-14-2: *Multiple ridged esker, 30 m high, in the North Arm of Kasmere Lake.*

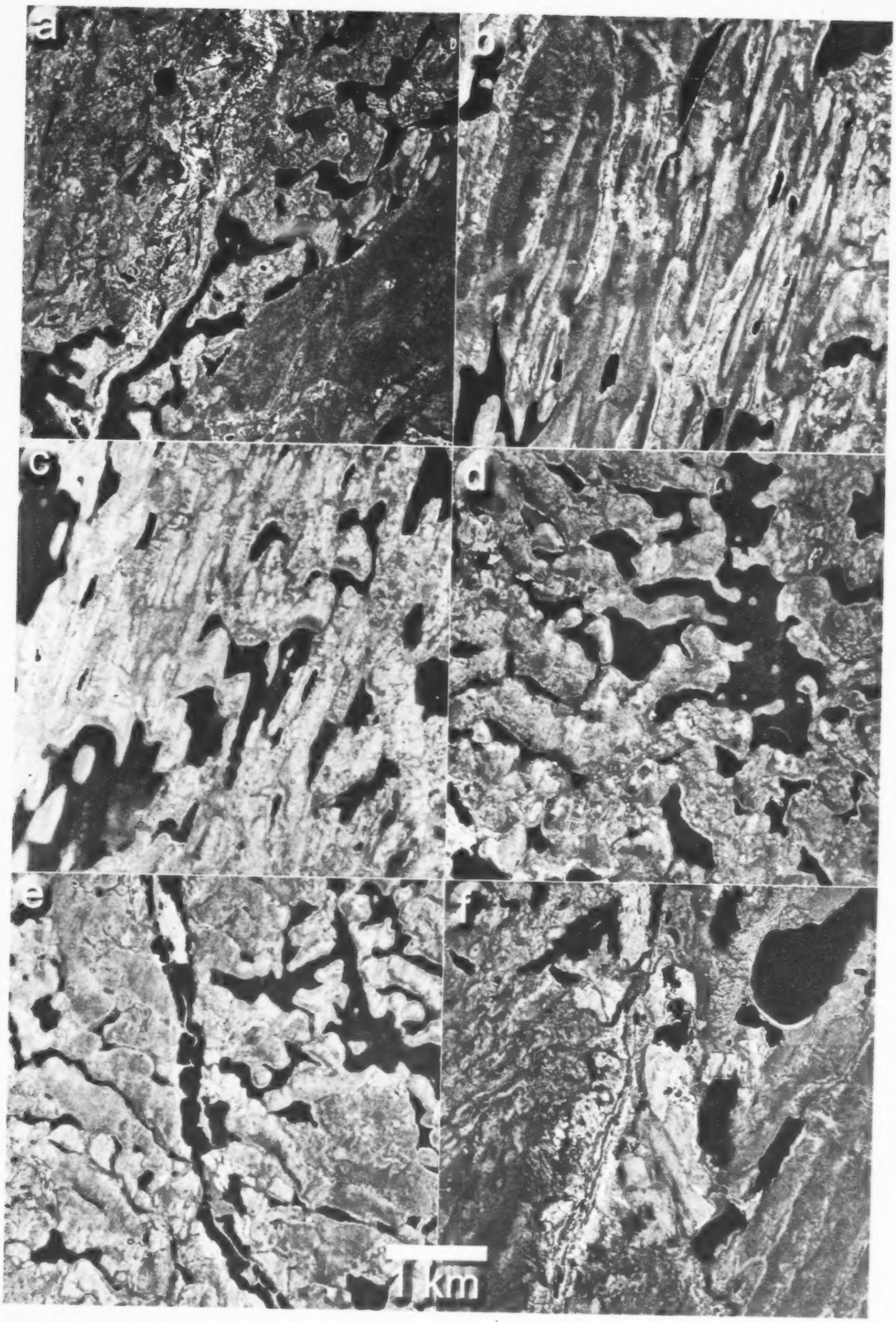

Figure GS-14-3: *Examples of landforms found in the map area:* ***a)*** *meltwater corridor, notice the increased number of lakes within the corridor;* ***b)*** *spindle drumlins;* ***c)*** *crescentic drumlins;* ***d)*** *Rogen moraines;* ***e)*** *tunnel channel, notice the small esker deposited within the tunnel channel;* ***f)*** *large esker ridge with associated fan deposits, notice that the esker has a prominent central ridge.*

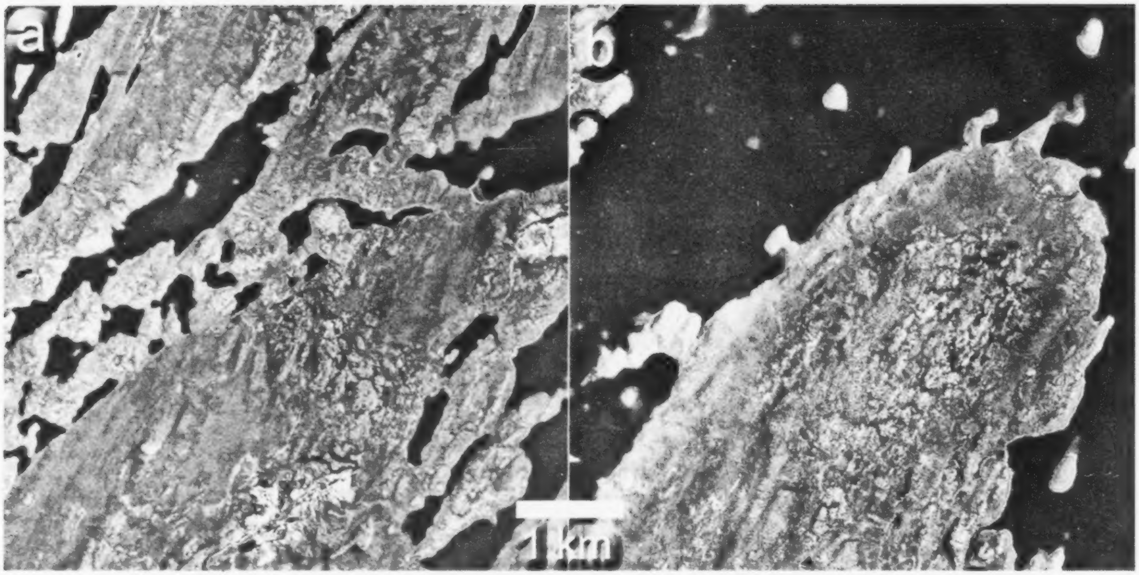

*Figure GS-14-4: Examples of meltwater corridors: **a)** a landform corridor cutting through a cluster of spindle drumlins, extending southwestward out of Koona Lake (on the right edge of the image); **b)** southern portion of Kasmere Lake, notice the spurs on the lakeshore and how they resemble the way in which the landforms in a) meet the edge of the meltwater corridor.*

probably between 1 and 5 km. Clast-supported open-framework boulder fields are commonly found in troughs between ridges. These boulder fields are, in part, depositional, probably having been eroded from the adjacent ridge. Counts and observations in eskers found largely exotic lithologies indicating a longer glacial transport for the eskers (Anderson et al., 2005).

Landform genesis

Turbulent subglacial meltwater played a major role in the formation of the present-day landscape in this area (Rampton, 2000; Campbell, 2002; Anderson et al., 2005). The model invoked for the development of the landforms in the Kasmere–Putahow lakes area is based on the meltwater hypothesis as described by J. Shaw (e.g., Shaw and Sharpe, 1987; Shaw, 2002), which suggests that erosion and deposition by glacial meltwater in the form of subglacial sheet floods is responsible for producing such landforms as drumlins, Rogen moraines and tunnel channels.

During the tens of thousands of year that this area was under glacial ice in the late Wisconsinan period, there was a buildup of glacial diamict (till) that is probably in excess of 5 m thick. During deglaciation, water began to accumulate in reservoirs under the glacier. This meltwater was periodically released in the form of turbulent sheet floods. These sheet floods caused the glacier to temporarily lift off from the diamict surface. Turbulence within the sheet flood was responsible for the bulk of the erosion, and the style of the vortices in any particular location largely determined the shape of the resultant landform. These vortices not only eroded into the diamict and bedrock surface, but also eroded a similar shape into the glacial ice above (Shaw, 2002). As the sheet flood passed and the volume of meltwater diminished, the glacier was progressively let down forcing the meltwater to organize into channels. This had two effects: 1) the areas where the glacier had been let down were protected from further erosion and this is probably where clusters of spindle drumlins are found, and 2) as the channels became narrower, the erosion intensified (Figure GS-14-3) due to the constriction and duration of flow. Eventually only tunnel channels remained open to meltwater flow. These channels are the narrowest and most deeply eroded, both in terms of diamict erosion and glacial ice erosion. Therefore, because glacial meltwater finds its course from high to low pressure within and below the glacier, and these tunnel channels would be relatively low pressure areas, when seasonal drainage within the glacier was re-established, esker conduits would likely re-occupy these tunnel channels.

This process is responsible for a continuum of landforms from drumlins to crescentic drumlins to Rogen moraines to tunnel channels. Eskers are not part of the continuum. They are deposited in the tunnel channels after the sheet flood has passed and seasonal drainage has been re-established. This continuum of landforms can have a depositional origin in other areas (Shaw, 2002), however, in the Kasmere–Putahow lakes area the continuum appears to be erosional, with the possible exception of Rogen moraines.

Numerous models have been invoked for the formation of Rogen moraines. Sarala (2005) suggested that with the glacier frozen to the substrate, plucking and stacking of sediments and bedrock blocks could generate Rogen moraines. This model predicts a very short glacial transport distance for the glacial debris, from 50 to 300 m, and probably the presence of angular boulders on and in the Rogen moraines. Angular boulders were not observed in Rogen moraines in the Kasmere–Putahow lakes area Fisher and Shaw (1992) cut trenches through Rogen moraines in Newfoundland and discovered that the internal bedding of the features was conformable with the upper surface of the Rogen moraine and as a result concluded that they were a depositional landform, which they believe was deposited by hyperconcentrated and subaqueous debris flows within a subglacial sheet flood. In this study, in the absence of natural exposures, landform analysis is unfortunately restricted to aerial photography interpretation, surface observations and observations within 1 m deep hand-dug holes.

In the Kasmere–Putahow lakes area, with the observed landform associations, it would appear difficult to invoke a glacial thrusting model for the formation of the Rogen moraines, however, it is possible, within a meltwater corridor, that the Rogen moraines began to migrate down flow and that they were, in part, deposited by hyperconcentrated meltwater.

Economic considerations

Geochemical surveys in the Kasmere–Putahow lakes area have defined anomalous values of Co, Cr, Cu, Fe, Mo, Ni, Zn, Pb and U. Mineral exploration by private exploration companies and field mapping by the MGS have discovered showings of uranium, gold and sulphides. For exploration purposes, it is important in glaciated areas to understand ice flow patterns. In the Kasmere–Putahow lakes area, landscape analysis has shown that when hand sampling near-surface glacial sediments in this area, it is important to understand the distribution of subglacial meltwater flow corridors when determining the bedrock source for potential mineral anomalies. These corridors can deviate significantly from the ice-flow direction as determined from glacial striations. These corridors can be traced parallel to streamlined drumlinoid landforms and perpendicular to transverse landforms such as Rogen moraines. Landform and diamict analysis also suggests a very short sediment transport distance, possibly less than a kilometre, at least in the near-surface diamict. The sediments found in eskers have been transported a long distance and this in combination with the meandering nature of an esker makes it difficult to determine a bedrock source for anomalous mineral-bearing sediments found in eskers.

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GS-15 Update and economic significance of geological mapping in the Garner–Gem lakes area, Rice Lake greenstone belt, southeastern Manitoba (NTS 52L11 and 14)

by S.D. Anderson

Anderson, S.D. 2006: Update and economic significance of geological mapping in the Garner–Gem lakes area, Rice Lake greenstone belt, southeastern Manitoba (NTS 52L11 and 14); *in* Report of Activities 2006, Manitoba Science, Technology, Energy and Mines, Manitoba Geological Survey, p. 155–169.

Summary

In the 2006 field season, a six-week program of 1:20 000 scale bedrock mapping was completed in the Gem Lake area in order to extend detailed mapping coverage into the poorly understood and complex areas east of the Manigotagan River between Garner Lake and Gem Lake, and south of Gem Lake between Lily Lake and Slate Lake. This work, which included concurrent sampling for lithogeochemistry and U-Pb geochronology, has resulted in a better understanding of the rock types, stratigraphy, structure and deformation history of the various supracrustal assemblages in the Garner–Gem lakes area. The nature, distribution and stratigraphic setting of FII–FIII rhyolite (Anderson, 2005), which exhibits evidence of volcanic-hosted massive sulphide (VHMS) potential, have also been significantly clarified. In addition, this work provides an improved geological context for a series of locally auriferous stockwork-breccia quartz-vein systems north of Gem Lake. One of these systems can be traced for 1.2 km along strike and appears to be developed along a brittle fault in the footwall of a first-order, domain-bounding shear zone that coincides with a map-scale transition from greenschist- to amphibolite-facies regional metamorphism. Similar transitions are spatially associated with major lode-gold deposits in other Archean greenstone belts and are considered to indicate areas of enhanced exploration potential.

Introduction

The Rice Lake greenstone belt is situated in the western Uchi Subprovince of the Archean Superior Province, and is flanked to the north by the ca. 3.0 Ga North Caribou continental terrane and to the south by ca. 2.69 Ga paragneiss and granitoid plutons of the English River Subprovince (Figure GS-15-1). The Rice Lake belt consists mainly of Meso- and Neoarchean, mafic to intermediate volcanic and volcaniclastic rocks, constituting several distinct lithotectonic assemblages (e.g., Poulsen et al., 1996; Bailes et al., 2003). In the southeastern Rice Lake belt, these assemblages include the Mesoarchean Garner assemblage and the Neoarchean Bidou, Gem and Edmunds assemblages, which provide a punctuated record of magmatism, sedimentation and orogenesis spanning roughly 200 m.y.

In 2002, the Manitoba Geological Survey initiated a program of bedrock mapping, structural analysis, lithogeochemistry, Sm-Nd isotope studies and U-Pb geochronology in the geologically complex and poorly understood Garner–Gem lakes area, which is located 45 km southeast of Bissett, Manitoba, in the southeastern extremity of the Rice Lake greenstone belt (Figure GS-15-1). This area contains key exposures of the principal supracrustal assemblages in the southeastern Rice Lake belt, and thus represents an important area for understanding the tectonostratigraphy, tectonic evolution and metallogeny of the belt as a whole (e.g., Corkery, 1995). The results of fieldwork completed at Garner Lake in 2002 and 2003 were summarized by Anderson (2002, 2003a) and presented on Preliminary Map PMAP2003-1 (Anderson, 2003b). Anderson (2005) summarized the preliminary results of reconnaissance geological mapping and lithogeochemistry in the Gem Lake area, which was completed during portions of the 2003, 2004 and 2005 field seasons.

In 2006, approximately 6 weeks of 1:20 000 scale geological mapping were conducted at Gem Lake in order to extend the mapping coverage outward from the shoreline bedrock exposures mapped during the 2003–2005 reconnaissance work. The mapping was mainly focused on the poorly understood area east of the Manigotagan River between Garner Lake and Gem Lake (Figure GS-15-2) and the geologically complex Lily–Slate lakes area south of Gem Lake. The goals of this mapping program were to 1) gain a better understanding of the rock types, stratigraphy, structure and deformation history of the various supracrustal assemblages, with particular emphasis on their contact relationships; 2) further document the nature and distribution of FII and FIII (Lesher et al., 1986) rhyolitic volcanic rocks described by Anderson (2005) and assess their VHMS potential; and 3) update the lithostratigraphic, tectonic and metallogenic framework for the southeastern Rice Lake belt.

To complement the existing geochemical database, 30 representative samples of least-altered volcanic rock types were collected in 2006 and analyzed for a full suite of major, trace and rare earth elements (REE) by instrumental neutron activation and inductively coupled plasma–mass spectrometry. In addition, two samples of felsic volcaniclastic rocks were collected for U-Pb geochronological analysis to further constrain the age of volcanism and sedimentation in the southeastern Rice

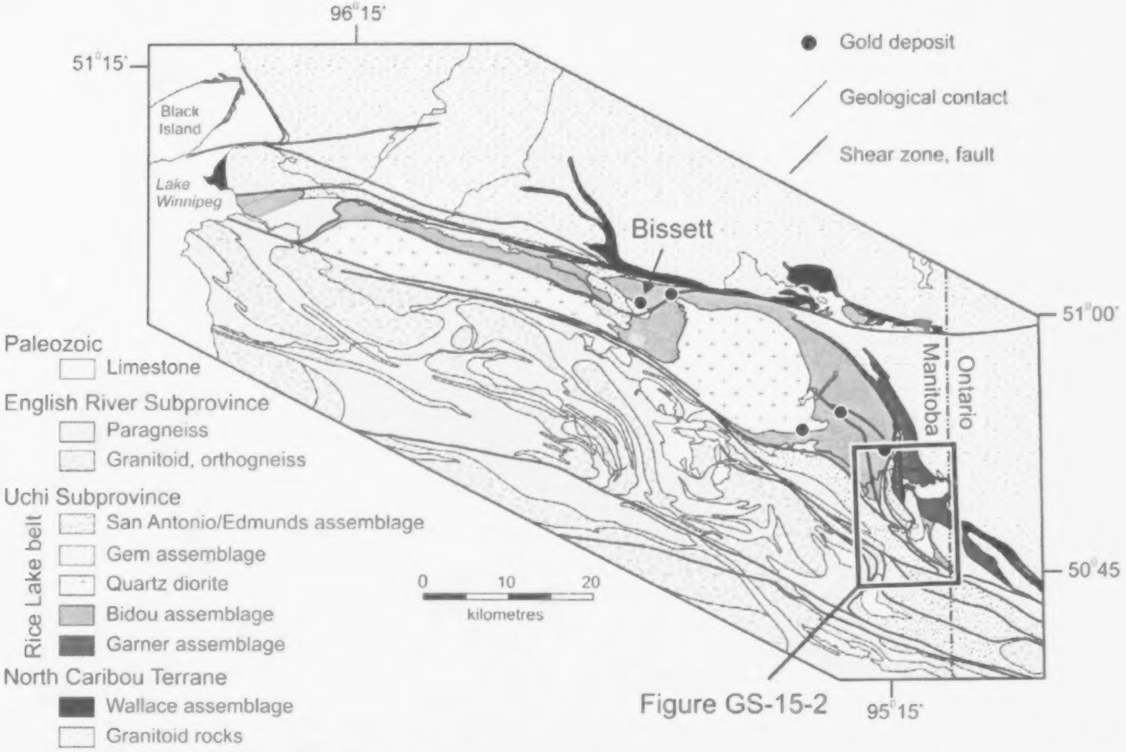
96°15'
51°15'
Black Island
Lake Winnipeg
Bissett
Gold deposit
Geological contact
Shear zone, fault
51°00'
50°45'
Manitoba
Ontario
95°15'
Figure GS-15-2
0
10
20
kilometres
Paleozoic
Limestone
English River Subprovince
Paragneiss
Granitoid, orthogneiss
Uchi Subprovince
Rice Lake belt
San Antonio/Edmunds assemblage
Gem assemblage
Quartz diorite
Bidou assemblage
Garner assemblage
North Caribou Terrane
Wallace assemblage
Granitoid rocks

Figure GS-15-1: *Simplified regional geology of the Rice Lake greenstone belt, showing the principal lithotectonic assemblages and the location of Figure GS-15-2.*

Lake belt. In this report, the results of the 2006 mapping program are incorporated with the results of previous mapping and lithogeochemistry to provide an updated geological framework for the Garner–Gem lakes area.

Structural framework

As described by Anderson (2003a, 2004), mesoscopic overprinting relationships indicate at least six generations of ductile deformation structure in the eastern portion of the Rice Lake greenstone belt. In the Garner–Gem lakes area, the map patterns of the various supracrustal assemblages define a series of generally northwest-trending, relatively low-strain lithostructural domains, separated by a complex network of ductile and ductile-brittle high-strain zones (Figure GS-15-2). Of these, the Beresford Lake Shear Zone (BLSZ) represents the most significant and apparently long-lived structural discontinuity (e.g., Brommecker, 1996; Anderson, 2003a). East of the BLSZ, generally north-younging rocks of the Garner assemblage are juxtaposed to the south across the West Garner Shear Zone (WGSZ) with generally west-younging rocks of the Bidou and Gem assemblages. The Garner assemblage is juxtaposed to the east, across the East Garner Shear Zone (EGSZ), with an extensive granitoid domain of uncertain age and affinity.

Mesoscopic evidence of extreme transposition is abundant throughout the mapped area and, on a macroscopic scale, is indicated by the fact that stratification within many of the lithostructural domains is oriented oblique to the trend of the bounding shear zones. West of the BLSZ, macroscopic map patterns and younging criteria in the Neoarchean succession, comprising the Bidou, Gem and Edmunds assemblages, define the regional-scale Beresford Lake anticline (BLA), which is the dominant structural feature in the core of the Rice Lake belt. The BLA is a tight, upright, doubly plunging, F_3-generation fold that trends northwest and is overturned to the southwest. The BLA is associated with a regionally developed, axial-planar, S_3 flattening fabric that dips subvertically and contains a steeply plunging L_3 elongation lineation. The S_3 fabric is consistently overprinted at a counter-clockwise angle by a penetrative, regional, S_4 crenulation cleavage. The resulting L^3_4 intersection lineation is pervasive in the map area and is generally oriented subparallel to L_3. Both of these fabrics are overprinted at a clockwise angle by a variably developed shear band or fracture cleavage that exhibits a consistent dextral sense of asymmetry or offset, and is particularly well developed adjacent to the BLSZ. This fabric is attributed to D_5 deformation. In the southeastern portion of the Rice Lake belt, all of these fabrics

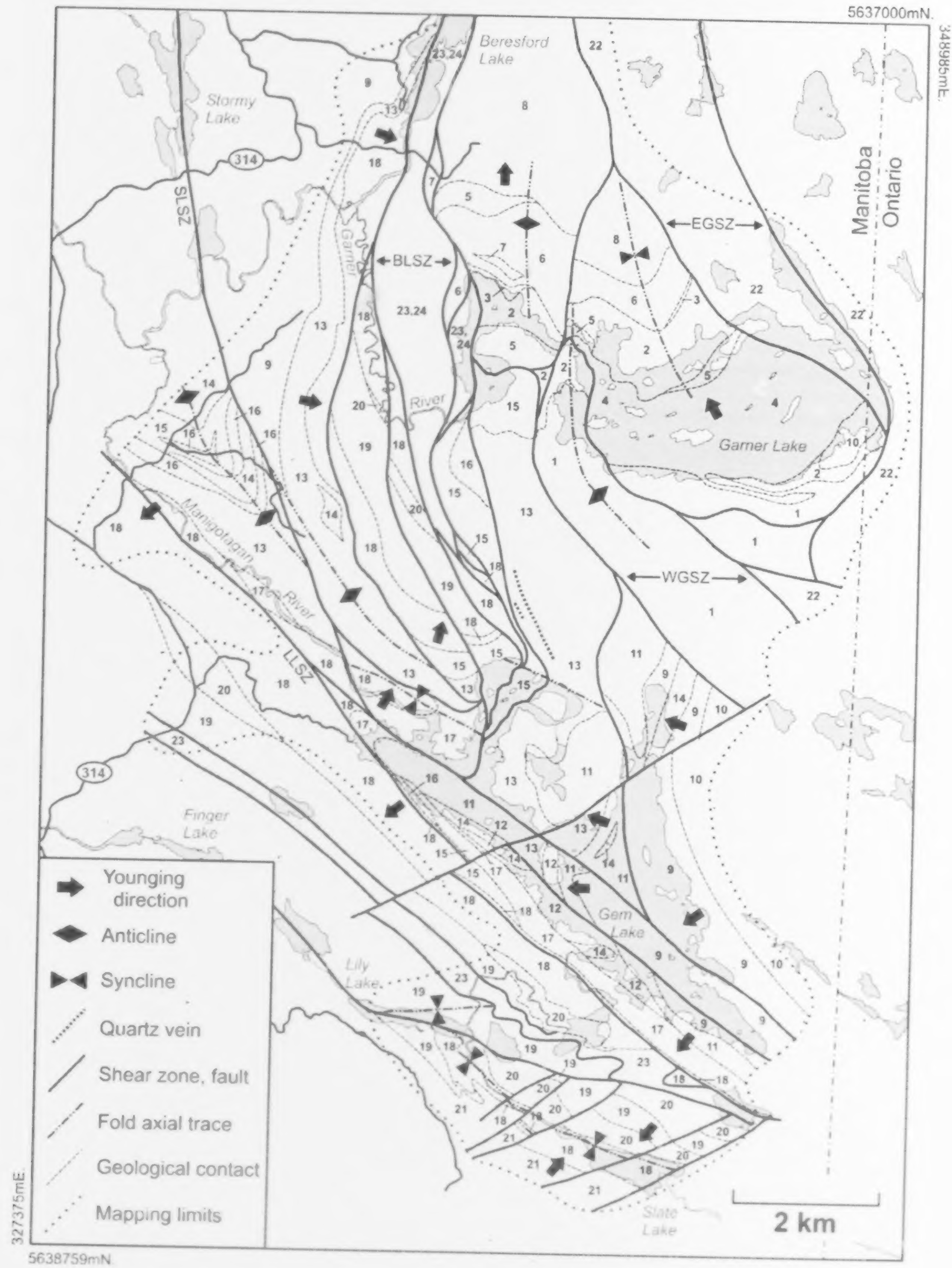
5637000mN
348985mE
Beresford Lake
Stormy Lake
314
SLSZ
Garner
River
BLSZ
EGSZ
WGSZ
LLSZ
Manitoba
Ontario
Garner Lake
Manigotagan River
Finger Lake
Lily Lake
Gem Lake
Slate Lake
2 km
327375mE
5638759mN
Younging direction
Anticline
Syncline
Quartz vein
Shear zone, fault
Fold axial trace
Geological contact
Mapping limits

***Figure GS-15-2:** Simplified geology of the Garner–Gem lakes area, southeastern Rice Lake greenstone belt. Refer to Table GS-15-1 for unit codes and descriptions. Abbreviations: BLSZ, Beresford Lake Shear Zone; EGSZ, East Garner Shear Zone; LLSZ, Long Lake Shear Zone; SLSZ, Stormy Lake Shear Zone; WGSZ, West Garner Shear Zone.*

Table GS-15-1: Assemblages, unit codes and rock-types, Garner–Gem lakes area, southeastern Rice Lake greenstone belt.

24. Gabbro, diorite; post-tectonic dikes
23. Tectonite, phyllonite, mylonite; chlorite-sericite ± ankerite altered
22. Undivided granitoid intrusive rocks and orthogneiss

EDMUNDS ASSEMBLAGE (ca. 2705–2710 Ma)

21. Basalt and basaltic andesite
20. Conglomerate
19. Subarkose, quartz greywacke
18. Greywacke-mudstone turbidite

Depositional contact

GEM ASSEMBLAGE (ca. 2720 Ma)

17. White to light grey dacite; feldspar-phyric
16. Bedded epiclastic rocks
15. Basalt and basaltic andesite
14. Gabbro, diorite
13. Buff to grey dacite and rhyolite; quartz and feldspar-phyric
12. Grey to black rhyolite; aphyric
11. Buff to white to pink rhyolite; quartz-phyric to aphyric
10. Leucogranite

Depositional contact

BIDOU ASSEMBLAGE (ca. 2730 Ma)

9. Intermediate to felsic volcanic and volcaniclastic rocks

Tectonic contact

GARNER ASSEMBLAGE (ca. 2870–2900 Ma)

Garner Lake extrusive complex (ca. 2870 Ma)

8. Calcalkalic basalt and basaltic andesite
7. Mg-tholeiitic basalt
6. Ultramafic komatiite and komatiitic basalt

Garner Lake intrusive complex (2870 Ma)

5. Mafic intrusive rocks
4. Ultramafic intrusive rocks

Garner Narrows unit (ca. 2883–2898 Ma)

3. Iron formation
2. Intermediate to felsic volcaniclastic rocks
1. Heterolithic volcaniclastic and epiclastic rocks

are overprinted by open, east- or northeast-trending F_6 folds and coeval east-southeast-trending, dextral high-strain zones.

The domain-bounding shear zones contain early zones of cohesive mylonite and ultramylonite that contain steeply plunging stretching and quartz-ribbon lineations, and preserve kinematic evidence of northeast-over-southwest dip-slip shear. These fabrics are generally overprinted by chloritic mylonite and tectonite that contain shallow lineations and well-developed kinematic indicators on horizontal surfaces, indicating transcurrent shear deformation. These relationships are interpreted to indicate that the main shear zones record at least two increments of ductile, noncoaxial deformation. At Gem Lake, structures associated with late-stage transcurrent shear deformation (regional D_5-D_6), including east-southeast-trending dextral high-strain zones, mesoscopic and macroscopic z-asymmetric folds, and late brittle faults, overprint and reactivate early high-strain fabrics. The resulting complex map patterns, which more than likely include complexities related to primary deposition in an active volcanic-arc terrane, as well as the effects of early (i.e., F_1) transposition, remain poorly resolved.

Metamorphic mineral assemblages west of the BLSZ and southwest of the WGSZ indicate peak metamorphism in the low- to middle-greenschist facies. South of Garner Lake, the hornblende and garnet isograds closely coincide with the WGSZ, and indicate an abrupt increase to peak amphibolite-facies metamorphism northeast of the shear zone, consistent with observed northeast-over-southwest kinematic indicators.

Description of units

The geology of the Garner–Gem lakes area is described below in order of decreasing known or inferred age of the constituent rock units. Unit numbers in this report correspond to those on Preliminary Map PMAP2006-7 (Anderson, 2006). For simplicity, only the principal map units are shown on Figure GS-15-2. The reader is referred to PMAP 2006-7 (Anderson, 2006) for the locations and distributions of the subunits described below.

Garner assemblage

The Mesoarchean Garner assemblage extends north and southeast of Garner Lake, and is subdivided into the Garner narrows unit and the Garner Lake intrusive and extrusive complexes. The Garner narrows unit is thought to form a conformable, north-younging stratigraphic succession that is at least 3.0 km thick and consists of heterolithic volcaniclastic and epiclastic rocks (unit 1) at the base, overlain to the north by intermediate to felsic volcaniclastic rocks (unit 2) and capped by iron formation (unit 3). The Garner narrows unit is intruded by peridotite (unit 4) and gabbro (unit 5) of the Garner Lake intrusive complex (GLIC). The Garner Lake extrusive complex (GLEC) disconformably overlies the Garner narrows unit and consists of a north-facing succession, more than 3.0 km thick, of subaqueous komatiitic (unit 6), Mg-tholeiitic (unit 7) and calcalkalic basalt (unit 8) flows and related subvolcanic intrusive rocks that are interpreted to be comagmatic with the underlying intrusive complex.

Garner narrows unit

Heterolithic volcaniclastic and epiclastic rocks (unit 1)

The base of the Garner assemblage is interpreted to be defined by a highly tectonized, heterogeneous package of volcaniclastic and epiclastic rocks that is best exposed along the southern and western shorelines of the east basin of Garner Lake, where it is intruded by peridotite and gabbro of the GLIC. This unit is also observed in widely spaced outcrops in the poorly exposed area south of Garner Lake and is interpreted to stratigraphically underlie volcaniclastic rocks of unit 2. Most outcrops exhibit intense L-S tectonite fabrics, with local evidence of extreme transposition; consequently, the stratigraphic thickness, internal stratigraphy and structure of this unit remain poorly resolved.

The southern portion of this unit consists mainly of heterolithic breccia and tuff-breccia, composed mainly of mafic to intermediate volcanic detritus (subunit 1a) with minor intercalations of intermediate to felsic breccia and tuff-breccia. To the northeast, these rocks appear to be overlain by an ~300 m thick unit of homogeneous rhyolite crystal tuff (subunit 1b) that weathers buff or grey and locally contains a faint stratification defined by beds of crystal-lapilli tuff up to 10 cm thick. These rocks are overlain by a unit of volcanic conglomerate (subunit 1c) that ranges up to at least 400 m thick and contains a very heterolithic population of angular to well-rounded, matrix-supported clasts that range up to 50 cm across. Along the western shoreline of Garner Lake, the conglomerate is interstratified and apparently overlain by a 200 m thick unit of thin-bedded feldspathic greywacke and mudstone (subunit 1d). The greywacke beds, which are typically less than 10 cm thick, are very fine to medium grained and contain 10 to 30% broken plagioclase crystals, with <5% quartz. Normal-graded beds are common and mainly fine toward the west. The overall features of unit 1 appear to be consistent with deposition in proximity to an actively eroding volcanic-arc terrane.

Intermediate to felsic volcaniclastic rocks (unit 2)

Intermediate to felsic volcaniclastic rocks crop out along the north and, to a lesser extent, south shores of Garner Lake, and form a section more than 1 km thick. The predominant rock types are dacite and rhyolite breccia and tuff-breccia (subunit 2a), with subordinate layers of lapilli tuff and crystal tuff, which define a roughly east-trending stratification in this unit. The breccia is characterized by a coarse, monolithic fragmental texture defined by very angular to subrounded, generally equant, unsorted fragments that range in size up to 25 cm (typically 1–5 cm). The fragments consist of light grey, aphanitic to fine-grained dacite and rhyolite that contain up to 5% plagioclase and/or hornblende phenocrysts. In Garner narrows, this unit consists mainly of massive, light grey dacite crystal tuff, which contains up to 15% subhedral plagioclase crystals, with minor intercalations of light green, aphyric andesite tuff-breccia (subunit 2b) and thinly layered quartz arenite, iron carbonate and fine-grained ferruginous argillite (subunit 2c). Uranium-lead analyses of zircons from a sample of relatively coarse plagioclase-phyric tuff indicate that emplacement most likely occurred between ca. 2883 and 2898 Ma (Anderson, unpublished data, 2003). Geochemically, these rocks exhibit an affinity to modern calcalkaline continental-arc volcanism.

Iron formation (unit 3)

Unit 2 is overlain to the north by a laterally discontinuous iron formation. In western Garner Lake, this unit consists of thinly layered magnetite-chert iron formation (subunit 3a) that can be traced along strike for more than 700 m and ranges up to 50 m thick. The contact with the underlying dacite was observed in one location and appears depositional. To the east, the iron formation is considerably less thick, not as laterally continuous and includes magnetite, silicate and local sulphide facies (subunit 3b). The iron formation everywhere separates dacitic volcaniclastic rocks from overlying spinifex-textured komatiite flows, and is interpreted to mark a significant depositional hiatus subsequent to arc magmatism.

Garner Lake intrusive complex

Ultramafic intrusive rocks (unit 4)

The main body of the GLIC, which underlies the main basin of Garner Lake, consists of 100 to 400 m thick layers of rusty brown–weathering serpentinized peridotite (subunit 4a) and dark green-black clinopyroxenite (subunit 4b) that strike generally east and northeast, and dip moderately to the north (Scoates, 1971). Peridotite appears to predominate in the south, whereas clinopyroxenite predominates in the north. This portion of the complex was not examined in detail during the present mapping program, and the interested reader is referred to Scoates (1971) for a more detailed description.

Mafic intrusive rocks (unit 5)

The northern portion of the GLIC is quite heterogeneous and consists mainly of fine- to medium-grained melanocratic gabbro and medium- to coarse-grained leucogabbro (subunit 5a), with minor glomeroporphyritic gabbro (subunit 5c). Pegmatitic leucogabbro (subunit 5b) occurs within these rocks as irregular segregation pods with diffuse contacts, or as narrow (<2 m thick) dikes, locally with sharp planar contacts. The dikes are generally concordant with the igneous layering in the underlying ultramafic rocks and are interpreted to represent a late-stage magmatic segregation phase that formed, largely in situ, in the upper portion of the GLIC (Scoates, 1971). In the western portion of the complex, medium- to coarse-grained, buff to grey hornblende diorite, quartz diorite and tonalite (subunit 5d) are present along the northern contact, and characteristically exhibit a pseudofragmental texture that is interpreted to result from cataclastic deformation. A sample of the hornblende quartz diorite yielded a U-Pb zircon date of ca. 2870 Ma (Anderson, unpublished data, 2003), which overlaps the 2871 ±1 Ma age obtained by Davis (1994) from a pegmatitic gabbro sill in the main body of the complex and is considered to closely approximate the age of the GLIC. These ages also provide a minimum age for the Garner narrows dacitic volcaniclastic rocks.

Garner Lake extrusive complex

Ultramafic komatiite and komatiitic basalt (unit 6)

The base of the GLEC consists of an ~800 m thick, north-younging succession of ultramafic komatiite and komatiitic basalt flows. The komatiite weathers dark green to black to rusty brown, and is typically massive with a fine- to coarse-grained subophitic texture (subunit 6a). The massive flows contain minor intercalations of pillowed komatiitic basalt, as well as rare interflow breccia units and magnetite iron formation. These rocks typically contain less than 35% fine-grained plagioclase, which is interstitial to acicular crystals of actinolite (after pyroxene). Spinifex-textured komatiite (subunit 6b) occurs in irregular zones or discrete layers within massive komatiite. In these zones, the spinifex texture is defined by randomly oriented, acicular crystals of actinolite (after pyroxene) that range up to 5 cm long and form radiating clusters up to 10 cm across. In the southern portion of this subunit, the komatiite contains sills, dikes and irregular bodies of serpentinized peridotite and pyroxenite, which are interpreted to be roughly comagmatic with the komatiitic flows.

Mg-tholeiitic basalt (unit 7)

In the western portion of the GLEC, the komatiitic flows contain significant volumes of Mg-tholeiitic basalt flows, with minor intercalated flow breccia and interflow magnetite iron formation. Pillowed flows predominate over massive flows, and both are typically aphyric and nonamygdaloidal. The Mg-tholeiitic basalt weathers light green-grey to emerald green, and is characterized by a fine- to medium-grained, subophitic, equigranular texture. In some locations, these rocks contain a medium- to coarse-grained, spinifex-like texture defined by fibrous actinolite (after pyroxene) crystals up to 0.5 cm long.

Calcalkalic basalt and basaltic andesite (unit 8)

The upper portion of the GLEC consists of a north-younging succession of calcalkalic basalt and basaltic andesite flows that ranges up to at least 1.5 km thick. The basalt weathers light green-grey to buff and is typically aphyric and nonamygdaloidal, with a fine- to medium-grained, subophitic texture. Pillowed flows predominate over massive flows. The pillows are bun shaped and range in size from 0.1 to 0.5 m across, with well-defined, less than 3 cm thick, dark green to black aphanitic selvages and local calcsilicate alteration. The cores of the pillows are locally strongly epidotized and locally contain up to 20% light grey to pink variolites up to 3 cm in diameter. In rare instances, the pillow cores are also plagioclase phyric, with up to 5% plagioclase crystals.

Bidou assemblage

The Neoarchean Bidou assemblage consists of a thick (≥5.5 km) sequence of subaqueously deposited supracrustal rocks. The lower portion consists of laterally continuous units of massive and pillowed, mid-ocean-ridge basalt (MORB)–like tholeiitic basalt flows, alternating with units of well-bedded feldspathic greywacke, mudstone, chert and minor volcaniclastic rocks. These rocks occupy the core of the Rice Lake greenstone belt and are intruded by ca. 2730 Ma (Turek et al., 1989) quartz diorite dikes associated with the Ross River pluton. The uppermost unit of the Bidou assemblage, referred to as The Narrows Formation (Campbell, 1971), comprises a 2.5 km thick succession of coarse volcaniclastic rocks composed mainly of ca. 2730 Ma (Turek et al., 1989), calcalkaline, plagioclase-phyric andesite and dacite. Only the uppermost portion of The Narrows Formation occurs in the mapped area. These rocks (unit 9) crop out west of the BLSZ, on the east limb of the BLA. Similar rocks crop out along the east side of Gem Lake and are tentatively correlated with The Narrows Formation, although here they contain a laterally continuous unit of pillowed basaltic andesite and andesite flows that has not been observed west of the BLSZ.

Intermediate to felsic volcanic and volcaniclastic rocks (unit 9)

West of the BLSZ, The Narrows Formation consists of a thick (~1.0 km) succession of coarse volcaniclastic rocks that dips steeply to the west-northwest and is composed almost exclusively of light green to grey to locally buff, plagioclase-phyric andesite and dacite. Pebble and cobble volcanic conglomerate, with minor interbeds of feldspathic sandstone (subunit 9b), are the predominant rock types and are interstratified with discontinuous units of dacite breccia, tuff-breccia and lapilli tuff (subunit 9a). Younging criteria in two locations indicate tops to the east. The volcanic conglomerate is typically stratified on the outcrop scale and contains subangular to well-rounded clasts of texturally variable andesite and dacite that are typically less than 50 cm in maximum dimension (Figure GS-15-3a), but locally range up to more than 2.0 m across. The volcanic breccia is more monolithic

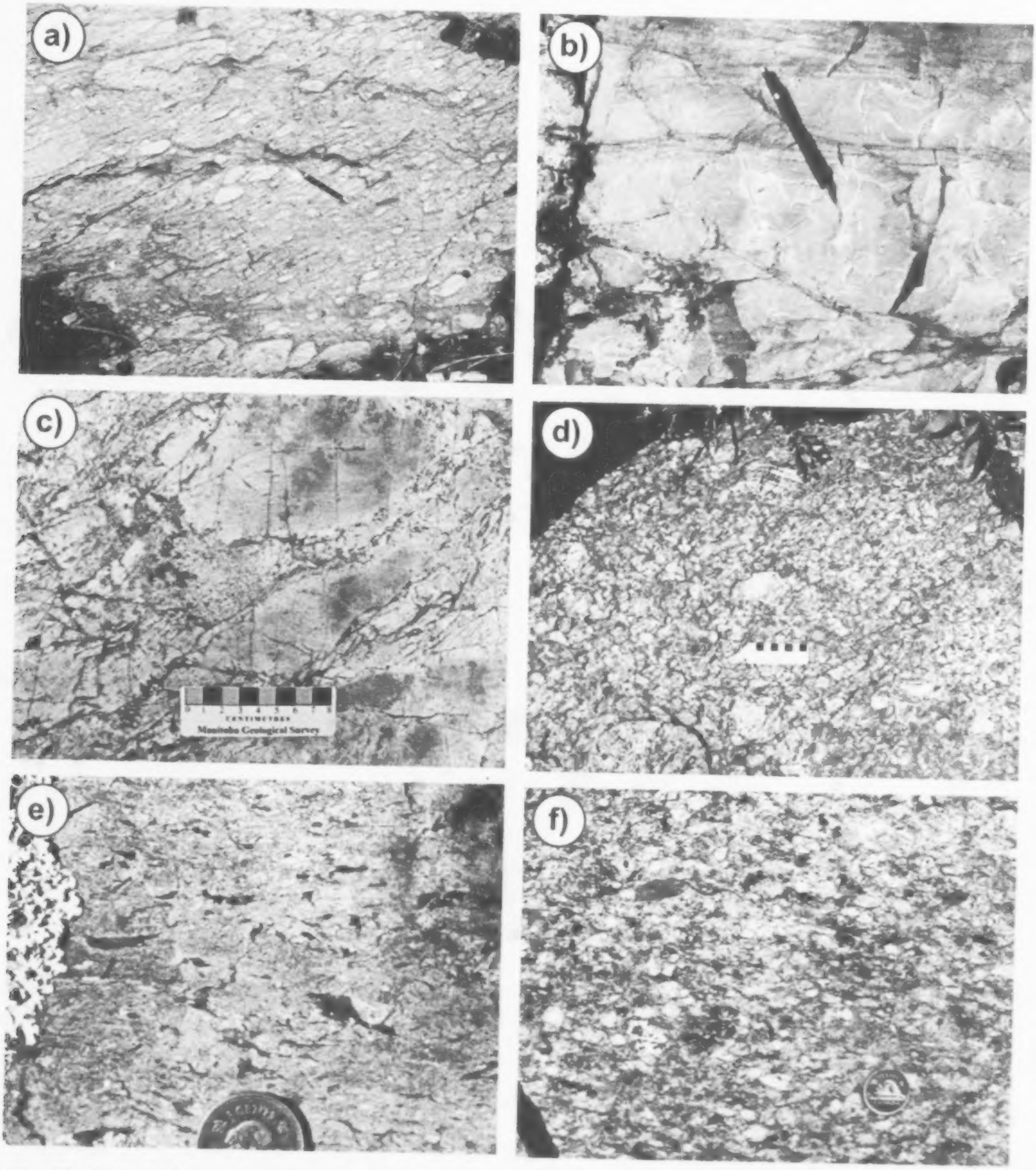

Figure GS-15-3: *Outcrop photographs of bedrock exposures from Gem Lake:* ***a)*** *layered dacite conglomerate (subunit 9b);* ***b)*** *massive white flow rhyolite (subunit 11a);* ***c)*** *intrusion breccia, composed of aphyric white rhyolite and fine-grained pink leucogranite (subunit 11d);* ***d)*** *tuff-breccia, composed of flow-banded rhyolite lapilli and blocks (subunit 12a);* ***e)*** *eutaxitic texture defined by dark, porphyritic fiamme in grey rhyolite lapilli tuff (subunit 12b);* ***f)*** *massive, heterolithic lapilli tuff (subunit 13d).*

and massive, and contains mainly angular to subrounded clasts.

East of the BLSZ, similar rocks define a homoclinal panel, up to 1.0 km thick, that dips to the southwest and west. Younging criteria consistently indicate that these rocks are upright. In this location, subunit 9a predominates at the base of the section and is overlain to the west by rocks of subunit 9b. Pillowed flows and minor pillow breccia composed of light green-grey to brown, aphyric to sparsely feldspar-phyric andesite (subunit 9c) define a 100 to 200 m thick unit that can be traced discontinuously for ~2.0 km along strike and appears to roughly coincide with the transition from subunit 9a to 9b. The pillows are bun shaped to amoeboid and typically range in size from 0.1 to 1.0 m, although an ~5.0 m long amoeboid 'mega-pillow' was observed in one outcrop. The pillows have well-defined dark green, aphanitic selvages that are less than 2 cm thick and have local calcsilicate alteration. Minor (<5%) interpillow material consists of chloritic epidotized hyaloclastite. The cores of the pillows are locally strongly epidotized and contain up to 20% round, quartz and/or epidote amygdules, 0.2 to 1.0 cm diameter.

Gem assemblage

The Neoarchean Gem assemblage overlies The Narrows Formation and consists of a thick succession of primary and variably reworked felsic to mafic volcanic flows and pyroclastic rocks that, at Gem Lake, ranges up to at least 2.0 km thick. Map patterns and contact relationships suggest a complex internal stratigraphy, which remains poorly understood. Given the relative lack of younging criteria and the complex, intense structural overprint, it remains possible that at least some of this complexity is due to structural repetition via out-of-sequence faulting or isoclinal folding. Hence, for the purpose of this report, the sequence of units described below should be taken as provisional.

At Gem Lake, the lower portion of the assemblage consists mainly of rhyolitic volcanic, volcaniclastic and intrusive rocks composed of high-silica, FII- and FIIIa-type (Lesher et al., 1986) tholeiitic rhyolite. On the basis of texture and colour, two units are distinguished: buff to white to pink quartz-phyric to aphyric rhyolite (unit 11) and overlying grey to black aphyric rhyolite (unit 12). Leucogranite plutons (unit 10) that intrude the Bidou and Garner assemblages along the eastern margin of the belt are chemically and texturally similar to the overlying unit 11 rhyolite, and are thus tentatively interpreted to be the subvolcanic equivalent. These rocks are overlain by a thick heterogeneous succession of coarse volcaniclastic rocks, with minor occurrences of flow-banded to massive flows composed of buff to grey, sparsely porphyritic, tholeiitic dacite and rhyolite (unit 13). Unit 14 consists of gabbro sills and dikes, which are compositionally and texturally similar to pillowed basalt and basaltic andesite flows and associated coarse volcaniclastic rocks of unit 15. These rocks are intimately intermixed and overlain by discontinuous intervals of well-bedded, heterolithic epiclastic rocks (unit 16). The uppermost portion of the Gem assemblage is locally marked by white to buff to light green-grey dacitic volcaniclastic rocks of calcalkalic affinity (unit 17).

Leucogranite (unit 10)

A small stock of equigranular biotite leucogranite (subunit 10a) is exposed in the southeastern portion of Garner Lake, where it discordantly intrudes the contact between the Garner narrows unit and serpentinized peridotite of the GLIC. The leucogranite is light pink to grey-white and is typically characterized by a fine- to medium-grained, equigranular phaneritic texture with less than 10% very fine grained biotite. The pluton is remarkably homogeneous and lacks xenoliths or late-stage crosscutting dikes. Along the margins, it contains a moderate to strong L>S fabric that is coaxial to the regional S-L fabric in the country rocks. A sample of this unit, collected during the 2003 field season for U-Pb geochronology, yielded a preliminary U-Pb zircon age of ca. 2723 Ma (Anderson, unpublished data, 2004).

At Gem Lake, the eastern margin of the mapped area is defined by a large leucogranite pluton that intrudes dacitic volcaniclastic rocks of unit 9. A narrow zone of hornfels is developed in the country rocks along the contact. The leucogranite is light pink to white and typically exhibits a medium-grained porphyritic texture defined by euhedral to subhedral phenocrysts of feldspar and distinctive blue-grey quartz (subunit 10b). Quartz phenocrysts range up to 5.0 mm and typically account for 20 to 40% of the rock. The matrix is very fine grained to aphanitic and contains <5% fine-grained biotite and magnetite.

Buff to white to pink rhyolite, quartz-phyric to aphyric (unit 11)

In the eastern portion of Gem Lake, the base of the Gem assemblage is defined by white- to pale yellow–weathering, aphyric rhyolite flows that range from massive (Figure GS-15-3b) to brecciated to flow banded and are associated with coarse monolithic breccia (subunit 11a). These rocks typically exhibit weak to moderate sericite alteration, with up to 5% finely disseminated to veinlet-controlled pyrite mineralization that is evidenced by patchy, moderate to intense gossan development on weathered outcrop surfaces. Along the south shore of Gem Lake and on islands and the main peninsula in the central part of the lake, these rocks are overlain by a heterogeneous interval of bedded epiclastic rocks (subunit 11b), which locally includes thin-bedded siliceous mudstone, laminated black chert, thick-bedded rhyolitic sandstone, monolithic rhyolite breccia and heterolithic pebble conglomerate or tuff-breccia. The latter rock type ranges up to 50 m thick on the east side of the large island in central Gem Lake and characteristically includes clasts of amygdaloidal basalt. Younging criteria indicate tops to the west. Along strike to the north, these rocks overlie a massive, ~150 m thick unit of coarsely quartz-phyric rhyolite breccia (subunit 11c) that locally exhibits a well-developed eutaxitic texture defined by up to 25% evenly distributed, dark grey-brown wispy fiamme (collapsed pumice?) and thus resembles a welded ignimbrite. Davis (1994) obtained a U-Pb zircon age of 2722 ±2 Ma from this breccia.

Toward the north, unit 11 is dominated by a white- to light pink–weathering intrusion breccia (subunit 11d) composed of white to grey, massive to flow-banded rhyolite and pink leucogranite (Figure GS-15-3c). These rocks were described as comagmatic "rhyolite agglomerate" and "felsite" by Weber (1971). The rhyolite contains up to 5% feldspar, 0.5 to 2.0 mm in size, and blue quartz phenocrysts in an aphanitic siliceous matrix, whereas the leucogranite is fine to medium grained and equigranular, and contains 10 to 20% blue quartz and 1 to 3% disseminated to fracture-controlled magnetite. The leucogranite forms the matrix to coarse breccia composed of angular, locally interlocking fragments of rhyolite, and also occurs as crosscutting dike-like bodies that contain rhyolite xenoliths. These rocks are tentatively interpreted to represent a near-surface subvolcanic intrusion (i.e., cryptodome).

Grey to black rhyolite, aphyric (unit 12)

Unit 12 consists of a distinctive package of dark grey to black, aphyric rhyolite flows and associated coarse fragmental rocks (subunit 12a) that is very well exposed along the south shoreline of Gem Lake, where it can be traced for ~2.5 km along strike. The rhyolite flows characteristically exhibit spectacular conchoidal fracture, flow banding and possible flow folding, and range up to 200 m in thickness. In the central portion of this unit, the flows are overlain to the southwest by a 50 to 60 m thick unit of massive, coarse monolithic breccia and tuff-breccia, which is composed of unsorted, angular, matrix-supported fragments of flow-banded grey rhyolite in a chloritic tuff matrix. Similar breccia units, ranging up to 30 m thick at the lateral extents of the rhyolite flows, may represent flow-foot breccia (Figure GS-15-3d). Subunit 12a is overlain by, and locally intercalated with, a distinctive unit of rhyolitic lapilli tuff and tuff-breccia (subunit 12b) that is characterized by a coarse eutaxitic texture defined by very irregular, wispy fiamme of dark grey to brown, sparsely quartz- or feldspar-phyric rhyolite, which are interpreted to represent collapsed pumice lapilli (Figure GS-15-3e). The top of unit 12 is defined by a well-stratified unit of epiclastic rocks (subunit 12c) that locally ranges up to 100 m thick and includes well-bedded, medium- to coarse-grained sandstone, mudstone and heterolithic pebble to cobble conglomerate composed mainly of grey rhyolite detritus. Graded beds and channels indicate tops to the southwest. The general features of this unit are consistent with effusive and pyroclastic rhyolite volcanism in a subaerial to shallow subaqueous setting.

Buff to grey dacite and rhyolite, sparsely quartz and feldspar-phyric (unit 13)

The main body of the Gem assemblage consists of a very heterogeneous package of felsic volcanic and volcaniclastic rocks that is composed mainly of buff to light grey, aphanitic to sparsely feldspar-phyric dacite and rhyolite. These rocks typically contain 2 to 5% of <2 mm, euhedral, white feldspar crystals in an aphanitic, siliceous, dark grey-black matrix with rare quartz phenocrysts. Fragmental buff to grey rhyodacite (subunit 13b), which typically consists of faintly stratified breccia, tuff-breccia, lapilli tuff and tuff, is the predominant rock type west of the BLSZ. These rocks range up to 500 m thick and include minor massive to flow-banded flows (subunit 13a) and intervals of well-bedded monolithic lapilli tuff, tuff and tuff-breccia (subunit 13c). East of the BLSZ, on the main peninsula in Gem Lake, these rocks are subordinate to thick intervals of heterolithic lapillistone and lapilli tuff (subunit 13d; Figure GS-15-3f), which typically lack mesoscopic evidence of stratification and include up to 10% basalt lapilli.

Gabbro, diorite (unit 14)

Units 11 to 13 are intruded by dikes and sills of gabbro and diorite that range up to 200 m thick in several locations. These rocks range from light green to dark green-black and from very fine to medium grained. Individual outcrops are typically massive, homogeneous and equigranular (subunit 14a). Along the south shore of Gem Lake, an ~200 m thick sill of dark green, fine-grained gabbro locally contains round quartz amygdules up to 0.5 cm across, indicating near-surface emplacement. Along the east limb of the BLA, thick sills of gabbro and diorite are characterized by a coarsely porphyritic texture defined by randomly oriented, closely packed, lath-shaped crystals of plagioclase that range up to 1.0 cm in size (subunit 14b; Figure GS-15-4a). Similar textures are observed in overlying pillowed flows, as well as in rounded gabbroic cobbles in overlying polymictic conglomerate of the Edmunds assemblage (Figure GS-15-4b).

Basalt and basaltic andesite (unit 15)

Unit 15 consists of volcanic and volcaniclastic rocks of basalt and basaltic andesite composition, which are interstratified with units 13, 16 and 17, and are only locally

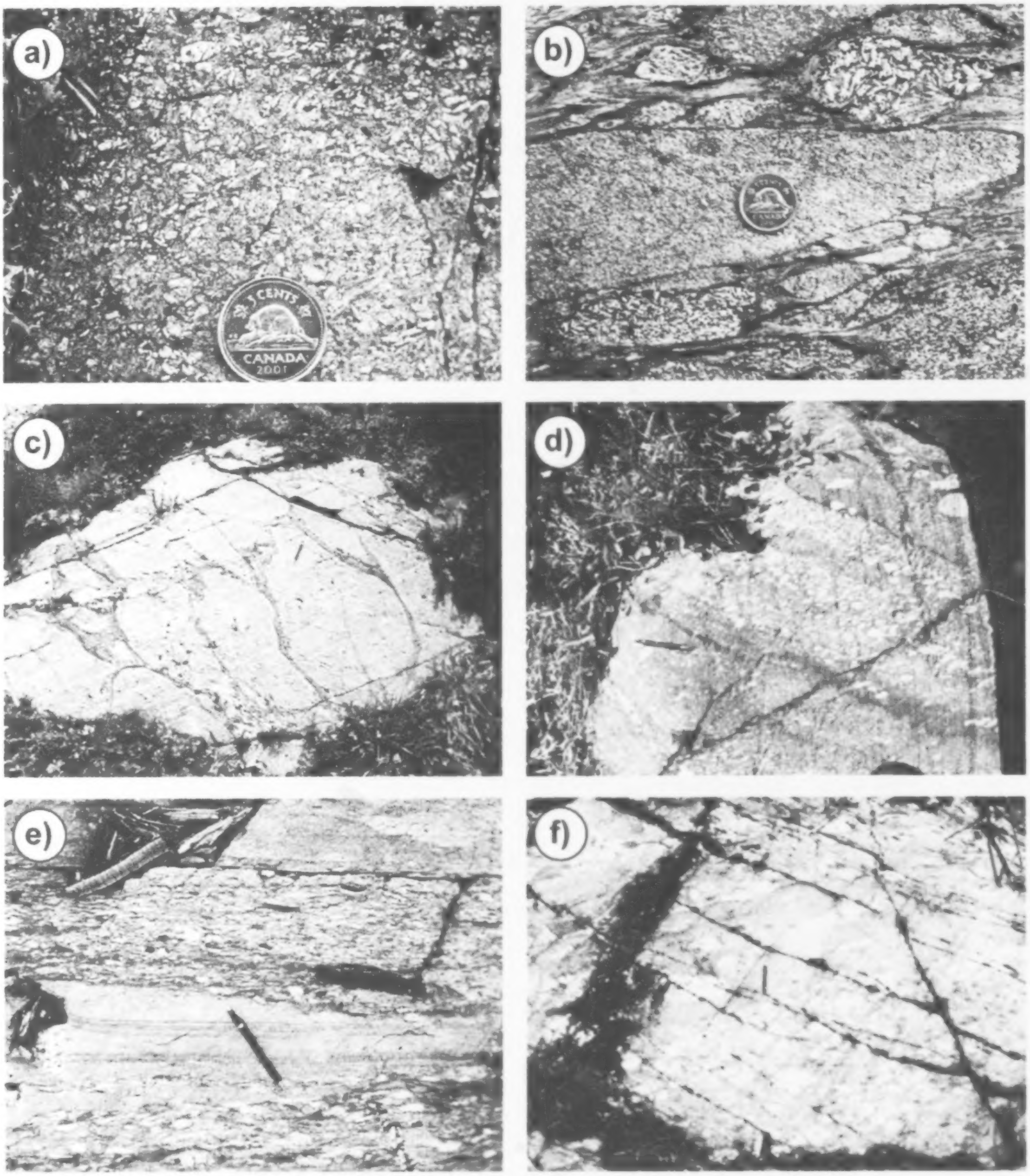

Figure GS-15-4: Outcrop photographs of bedrock exposures from Gem Lake and Slate Lake: ***a)*** *porphyritic gabbro (subunit 14b);* ***b)*** *porphyritic gabbro clasts in conglomerate (subunit 18b);* ***c)*** *pillowed basaltic andesite (subunit 15a);* ***d)*** *bedded pebble conglomerate (subunit 16b);* ***e)*** *bedded quartz greywacke and polymictic pebble conglomerate (subunit 19b; note scour at the base of the upper conglomerate bed, indicating tops upward in photo);* ***f)*** *faintly layered monolithic dacite conglomerate (subunit 20b).*

of sufficient thickness and strike length to define mappable units. These rocks are dark green to light grey-green to buff, fine to medium grained, and aphyric to coarsely plagioclase phyric. The plagioclase-phyric rocks contain 5 to 40% euhedral plagioclase crystals that are typically 1 to 5 mm in size but locally range up to 1.0 cm. Massive and pillowed flows (subunit 15a), which range up to 40 m thick, locally define the top of the Gem assemblage along the south shore of Gem Lake, and on the east limb of the BLA. On the west limb of the BLA, the flows are farther down-section, below a thick succession of fragmental dacite (unit 13). The pillowed flows typically exhibit well-preserved, bun-shaped pillows up to 1.5 m across, with only minor (<5%) interpillow hyaloclastite (Figure GS-15-4c). The flows characteristically contain 1 to 5%, round to slightly elongate, evenly distributed quartz amygdules that range up to 7.0 cm in size. In the northwest arm of Gem Lake, extending north to the west end of Garner Lake, this unit consists of monolithic (subunit 15b) and heterolithic (subunit 15c) fragmental rocks composed of variably plagioclase-phyric basalt and basaltic andesite.

Bedded epiclastic rocks (unit 16)

Basalt and basaltic andesite of unit 15 are locally intercalated with mappable units of thin-bedded, feldspathic greywacke-mudstone turbidite (subunit 16a) and thick-bedded, heterolithic, pebble to boulder conglomerate with minor coarse-grained sandstone (subunit 16b; Figure GS-15-4d). The best examples of this unit occur adjacent to the Manigotagan River on the west limb of the BLA, along strike to the southeast from similar rocks that were described in detail by Seneshen and Owens (1985) and Seneshen (1986, 1990). The greywacke beds are fine to medium grained and range up to 1.0 m thick, with locally well-developed normal grading and channels. Crossbedded greywacke is locally intimately intercalated with pillowed, vesicular mafic flows (e.g., Seneshen and Owens, 1985), indicating coeval mafic volcanism and sedimentation in a shallow subaqueous depositional environment. The conglomerate is matrix supported, poorly sorted and contains subangular to well-rounded clasts that are typically 10 to 30 cm in diameter but locally range up to 2.0 m. Swarms of fine-grained basalt and basaltic andesite dikes, which have well-developed chilled margins and are locally vesicular, are a characteristic feature of this unit and are interpreted as subvolcanic feeders for the associated mafic volcanic rocks.

Buff to white to light grey dacite, feldspar-phyric (unit 17)

This unit is best exposed is several large outcrops at the outlet of the Manigotagan River in northwestern Gem lake, and is also well exposed along the top of the high outcrop ridge that extends along the south shoreline of Gem Lake. In both locations, these rocks lie in sharp, clearly depositional contact with thin-bedded greywacke-mudstone turbidite of the overlying Edmunds assemblage. Massive dacitic crystal tuff, which weathers light grey-green to white to buff, is the predominant rock type and contains minor intercalations of monolithic breccia, tuff-breccia and lapilli tuff. The crystal tuff contains up to 20% of 2 to 5 mm, subhedral feldspar crystals, as well as 1 to 3% of <1.5 mm, anhedral quartz 'eyes'. These rocks are distinguished from the underlying tholeiitic felsic volcanic rocks of units 11 to 13 by their calcalkalic geochemical affinity. A sample of this material, from 15 m stratigraphically below the basal contact of the Edmunds assemblage along the Manigotagan River, was collected in 2006 for U-Pb geochronological analysis to constrain the age of the uppermost, calcalkalic portion of the Gem assemblage.

Edmunds assemblage

The Neoarchean Edmunds assemblage is at least 2.5 km thick and is composed of basinal siliciclastic rocks that consist mainly of monotonously bedded greywacke-mudstone turbidite (unit 18), with subordinate units of coarse quartz greywacke (unit 19), conglomerate (unit 20), and basalt (unit 21). The lower portion of the Edmunds assemblage is marked by a 1.2 km thick coarsening-upward cycle, suggesting deposition in a progradational subaqueous fan. Contact relationships indicate a significant depositional hiatus and erosional unconformity at the base of the Edmunds assemblage (Anderson, 2005). Uranium-lead dating of detrital zircons and crosscutting plutons (e.g., Corfu et al., 1995) constrain deposition to the ca. 2.71 ro 2.70 Ga time interval.

Greywacke-mudstone turbidite (unit 18)

The lower portion of the Edmunds assemblage consists of a thick succession of well-bedded greywacke-mudstone turbidite. In general, thinly interbedded mudstone and fine-grained greywacke (subunit 18a), with minor chert, predominate near the base of the assemblage, and are overlain up-section by thick-bedded, medium- to coarse-grained greywacke (subunit 18b), which contains subordinate interbeds of mudstone and polymictic pebble conglomerate. In several locations, the basal contact of the assemblage is well exposed and defined by a unit of thin-bedded to laminated cherty mudstone that is typically 1 to 2 m thick but locally ranges up to more than 100 m thick in places along the Manigotagan River, suggesting that a relatively sediment-starved, quiescent interval preceded basin infilling. Normal-graded beds and soft-sedimentary deformation features are common in these rocks.

Subarkose, quartz greywacke (unit 19)

Unit 19 consists of buff to light grey, medium to very coarse grained subarkose and quartz greywacke that typically contain 10 to 25%, angular to subrounded quartz grains and granules. On the east limb of the BLA, remarkably massive and homogeneous quartz greywacke (subunit 19a) ranges up to more than 100 m thick, with only rare mudstone beds and minor diffuse pebble lags defined by mudstone rip-ups and quartz pebbles. More commonly, these rocks consist of thickly bedded quartz greywacke (subunit 19b), with subordinate to subequal interbeds of polymictic conglomerate and thin-bedded greywacke and mudstone (Figure GS-15-4e). Individual quartz greywacke beds range up to 1.5 m thick and are separated by thin (<10 cm) beds of fine-grained greywacke or mudstone. These beds characteristically exhibit normal size grading and well-developed basal lag deposits composed of angular mudstone rip-up clasts, and more rounded lithic clasts and quartz pebbles. Lenticular layers of polymictic conglomerate range up to more than 2 m thick and contain unsorted, typically subangular to well-rounded, matrix-supported clasts that range in size up to 20 cm. South of Lily Lake, these rocks include a 1–5 m thick layer of magnetite-chert iron formation (subunit 19c) that can be traced for ~800 m along strike.

Conglomerate (unit 20)

Polymictic conglomerate (subunit 20a) forms layers up to at least 25 m thick within the massive to thick-bedded quartz greywacke of unit 19. This conglomerate ranges from matrix to clast supported, and massive to well layered on the scale of individual outcrops. It contains subangular to well-rounded, pebble- to cobble-sized clasts in a matrix of medium- to coarse-grained quartz greywacke. The clasts are mainly representative of the underlying volcanic rocks, suggesting relatively local provenance. Nevertheless, well-rounded clasts of coarse-grained tonalite and medium- to coarse-grained orthoquartzite, which do not appear to be of local provenance, are also locally common and suggest a probable source area in the ca. 3.0 Ga North Caribou Terrane. This inference is supported by the presence of ca. 3.0 Ga detrital zircons in a sample of Edmunds assemblage greywacke collected for detrital zircon U-Pb analysis (Anderson, unpublished data, 2005).

In the area between Slate Lake and Gem Lake, monolithic dacite conglomerate (subunit 20b), which was previously mapped as "rhyodacitic tuff-breccia" of the Gem assemblage by Weber (1971), is interstratified at a variety of scales with thick-bedded quartz greywacke (subunit 19b) and polymictic conglomerate (subunit 20a). This conglomerate, which ranges up to 400 m thick north of Slate lake, is massive to very faintly layered and composed of unsorted, well-rounded to subangular, matrix-supported clasts of buff- to light green–weathering, plagioclase-phyric dacite (Figure GS-15-4f). The clasts range in size up to 1.5 m but are typically 5 to 10 cm. No examples of obviously second-cycle (i.e., volcaniclastic) dacite clasts were observed. The matrix consists of medium- to coarse-grained feldspathic wacke that contains 30 to 40% subhedral feldspar crystals <1.5 mm in size. Locally, the conglomerate contains rare clasts of green plagioclase-porphyritic andesite. Along the upper and lower contacts, this conglomerate is locally heterolithic and contains minor interbeds of polymictic conglomerate and thin-bedded greywacke and mudstone. The overall features of these rocks are suggestive of subaqueous debris flow deposits that, on the basis of the apparent absence of second-cycle detritus, may have been sourced from an active (i.e., ca. 2.71 Ga) volcanic arc. A sample of this material was collected for U-Pb geochronological analysis of the detrital zircon population.

Basalt and basaltic andesite (unit 21)

This unit is most extensively exposed south of the Manigotagan River, between Lily Lake and Slate Lake. It consists mostly of mafic tectonite, composed of strongly foliated chlorite-carbonate phyllonite that is mainly derived from pillowed basalt and basaltic andesite flows (subunit 21a) and subordinate coarse fragmental rocks (subunit 21b). These rocks are buff to rusty brown to green, fine grained, and aphyric to locally sparsely feldspar phyric. Pillows preserved in low-strain enclaves within the tectonite are bun shaped to amoeboid, nonamygdaloidal and less than 1.0 m in maximum dimension, with <2 cm thick chloritic selvages and <5% interpillow material (mainly carbonate). South of the Manigotagan River between Lily and Slate lakes, the basalt lies in sharp concordant contact with overlying thin-bedded greywacke-mudstone turbidites that, along strike south of Lily Lake, contain interlayers of mafic crystal tuff. Basalt dikes are observed to crosscut all of the Edmunds assemblage rocks described previously, indicating that mafic volcanism was coeval with sedimentation.

Rocks of unknown lithotectonic affinity

Undivided intrusive rocks (unit 22)

At Garner Lake, the eastern limit of the mapped area is defined by a northwest-trending domain of undivided granitoid plutonic rocks and mixed orthogneiss, the western margin of which is defined by a 100 to 300 m thick zone of amphibolite-facies tectonite and mylonite that contains a penetrative and pervasive S-L fabric defined by acicular hornblende porphyroblasts (the East Garner Shear Zone). East of the shear zone, variably foliated hornblende-biotite quartz diorite, granodiorite and granite (subunit 22a) are the predominant rock types, and are transposed into thick domains of felsic orthogneiss (subunit 22b). Macroscopic lenticular domains of mafic orthogneiss (subunit 22c), which include enclaves of serpentinized peridotite and pyroxenite, are likely derived from the GLIC (units 4 and 5). This interpretation is supported by contact relationships along the northeastern margin of the GLIC, where hornblende-biotite granodiorite dikes are observed to crosscut melanocratic gabbro, and both are overprinted by the prominent gneissic fabric that characterizes the East Garner Shear Zone.

Tectonite, phyllonite, mylonite (unit 23)

In the central portion of the map area, the BLSZ contains thick zones of strongly altered tectonite, phyllonite and mylonite (unit 23), for which the precursor rocks are uncertain. The alteration minerals consist of strongly foliated, fine- to medium-grained chlorite and sericite, with abundant calcite and ankerite, and subordinate pyrite and chalcopyrite. The most intense alteration is characterized by up to 50% ankerite, which locally occurs as strongly boudinaged and discontinuous veins that range up to 50 cm thick and contain minor quartz, chlorite, sericite, calcite, pyrite and chalcopyrite. These alteration zones range up to more than 100 m thick and occur over a strike length of more than 9.0 km. In the area northwest of Garner Lake, macroscopic lenticular domains of lesser deformed and altered wallrock within the altered tectonite consist mainly of komatiitic and Mg-tholeiitic basalt flows, with strongly transposed segments of magnetite-facies iron formation of the adjacent GLEC.

Gabbro, diorite (unit 24)

Dikes of light grey, fine- to medium-grained gabbro and diorite are observed throughout the mapped area, but are particularly abundant along the trace of the BLSZ, where they are observed to discordantly cut penetrative tectonite and mylonite fabrics. The cores of the dikes exhibit an equigranular subophitic texture and are locally weakly plagioclase porphyritic. In several locations, the central portions of these dikes also contain subrounded to angular xenoliths of vein quartz up to 10 cm across. The contacts of the dikes are typically planar and parallel, with well-developed chilled margins up to 5 cm thick. In one location in the western portion of Garner Lake, delicate apophyses of diorite extend outward from the contact of a diorite dike that crosscuts chlorite-sericite-ankerite-altered tectonite along the eastern margin of the BLSZ. The apophyses, which are <1.0 cm thick, extend outward into the tectonite country rock for up to 15 cm and are apparently undeformed. These dikes are interpreted to postdate significant regional deformation in the southeastern Rice Lake greenstone belt.

Economic considerations

As described by Anderson (2005), felsic flows and vent-proximal fragmental volcanic rocks in the Gem assemblage are composed of FII- and FIIIa-type (Lesher et al., 1986) tholeiitic dacite, rhyolite and high-silica rhyolite, which exhibit high-field-strength-element signatures indicative of extension-related, within-plate volcanism. These rocks are provisionally interpreted to record subaerial to shallow subaqueous volcanism associated with the initiation of a ca. 2.72 Ga arc-rift basin within the Bidou volcanic arc. Type FII and FIII rhyolites host several important VHMS deposits in the Superior Province (Lesher et al., 1986), and the association of extension-related volcanism and VHMS deposits has been well documented in the literature (e.g., Lentz, 1998; Syme, 1998; Syme et al., 1999). These attributes indicate that, in addition to the demonstrated potential for orogenic lode-gold deposits, the Gem Lake area is prospective for VHMS deposits. The present study provides a much improved stratigraphic and structural context to further evaluate the VHMS potential of these rocks.

The area east of the Manigotagan River between Garner Lake and Gem Lake contains several documented occurrences of auriferous quartz-carbonate veins, most of which have been briefly examined by the author. All of the examined occurrences are hosted by discrete, ductile and brittle-ductile shear zones in close spatial association with the major southeast-trending, domain-bounding, high-strain zones that dominate the map pattern in the Garner–Gem lakes area. Hence, proximity to these zones appears to represent an important, property-scale exploration parameter. Detailed surface prospecting along these zones, with emphasis on sites of potential chemical or structural favourability, will prove useful in identifying additional exploration targets.

As described by numerous authors, lode-gold deposits in greenstone terranes typically show a distinct spatial association with zones of transition from lower to upper greenschist-facies regional metamorphism, which broadly coincide with the contemporaneous transition from brittle to ductile deformation (e.g., Kerrich and Cassidy, 1994). In this regard, the West Garner Shear Zone (WGSZ), which coincides with an abrupt, northeastward change from greenschist- to amphibolite-facies metamorphism, may be a particularly attractive exploration target. North of Gem Lake, the footwall of the WGSZ contains several zones of stockwork-breccia quartz veins, hosted by dacitic fragmental rocks (unit 13). One of these vein systems was briefly described by Russell (1952), who noted the occurrence of pyrite and arsenopyrite in quartz-carbonate veins. Noranda Exploration Co. Ltd. (Assessment File 92840) reported values of 15.5 and 5.1 g/t Au from grab samples of arsenopyrite-bearing quartz vein material from possibly the same zone, although subsequent sampling yielded a best result of 2.1 g/t Au. Two of these vein systems were examined during the 2006 field season, and appear to be developed on, and locally overprinted by, north-northwest-trending brittle faults that contain shallowly plunging slickenline lineations. The larger system was traced along strike for 1.2 km (Figure GS-15-2). In this system, a central quartz-breccia vein, which is typically 0.2 to 0.5 m thick, is bounded by 0.5 to 3 m thick zones of intensely silicified and crackle-textured wallrock (Figure GS-15-5a, b), and fringed outward by complex arrays of quartz-stockwork veins. The central breccia vein consists of smoky grey or white quartz that contains 1 to 2% finely disseminated to blebby pyrite, with a trace of chalcopyrite. Four samples of this material collected by the author failed to return any significant Au values. Perhaps significantly, these samples also lacked the coarse arsenopyrite noted by previous

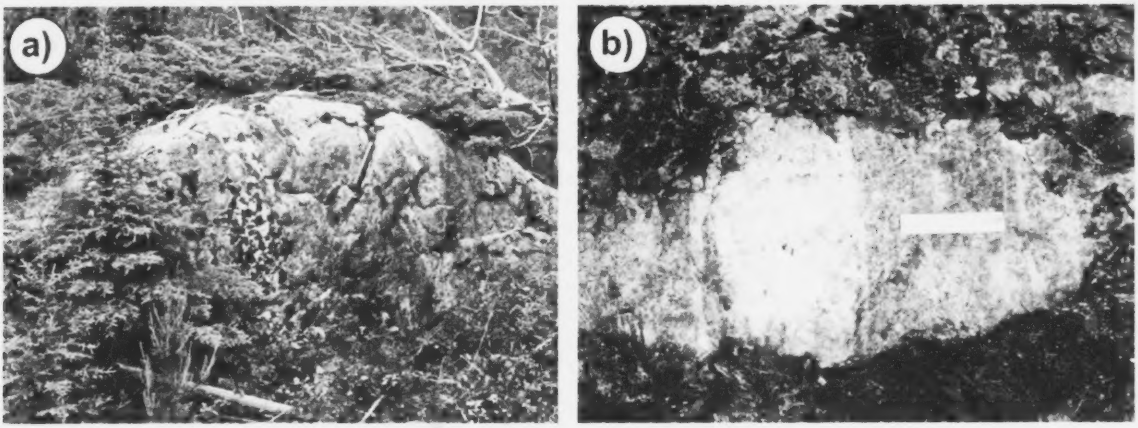

Figure GS-15-5: *Outcrop photographs of stockwork-breccia quartz veins north of Gem Lake:* ***a)*** *quartz-breccia vein (white) bounded by 2 to 3 m thick zones of intensely silicified wallrock;* ***b)*** *detail of quartz-breccia vein and crackle-textured, silicified wallrock.*

authors. In any case, the large extent of these vein systems suggests that the footwall of the WGSZ was a significant locus for hydrothermal fluid flow that, at least locally, appears to have transported and deposited gold.

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GS-16 Geology and structure of the Bird River Belt, southeastern Manitoba (NTS 52L5 and 6)

by M. Duguet[1], H.P. Gilbert, M.T. Corkery and S. Lin[1]

Duguet, M., Gilbert, H.P., Corkery, M.T. and Lin, S. 2006: Geology and structure of the Bird River Belt, southeastern Manitoba (NTS 52L5 and 6); *in* Report of Activities 2006, Manitoba Science, Technology, Energy and Mines, Manitoba Geological Survey, p. 170–183.

Summary

The Bird River Belt (BRB) of the Superior craton is situated between the English River Domain to the north and the Winnipeg River Domain to the south. In 2005, the Manitoba Geological Survey initiated a multidisciplinary program of targeted bedrock mapping, structural analysis, lithogeochemistry and U-Pb geochronology in the BRB. The objective of this program is to further refine the stratigraphic, structural and tectonic framework of the belt.

During the summer of 2006, field investigations on the north flank of the BRB focused on the structural relationships between the Maskwa Lake Batholith and the different units of the BRB. These investigations highlighted the importance of the Peterson Creek Shear Zone (PCSZ) in the structural framework of this part of the belt; the last movements of the PCSZ are coeval with the emplacement of the 2631 Ma Marijane Lake pluton. Stratigraphic investigations have not significantly changed the number of subdivisions, but their definitions and structural inter-relationships were completely revised. These revisions include the reassignment of the sequence in the north part of the BRB, which was previously attributed to Bernic Lake Formation, to the Peterson Creek Formation. Another part of the section was assigned to a new sedimentary unit composed of turbidite, chert, argillite and conglomerate, which apparently represents a sedimentary cover sequence overlying the Lamprey Falls Formation.

Further fieldwork was also undertaken on the south flank of the BRB in the vicinity of the Winnipeg River and Eaglenest Lake. Two major shear zones with contrasting kinematics have been identified in that area.

The structural and kinematic data resulting from the mapping in 2005 and 2006 indicate the BRB is a pop-up structure that is the result of a complex, polyphase transpressive tectonic history.

Introduction

The BRB is located in southeastern Manitoba, about 150 km northeast of Winnipeg. The BRB of the Superior craton is situated between the English River Domain to the north and the Winnipeg River Domain to the south. It is a significant district for ore deposits (e.g., the Tanco rare-element pegmatite deposit, the Maskwa Fe-Ni-Cu–platinum group element (PGE) deposit and the Dumbarton Ni-Cu-Zn-PGE deposit). This area has been explored for ore deposits since the 1920s; however, few regional geological maps that include the BRB have been published (Davies, 1956; Trueman 1980; Cerny et al., 1981) and the available maps display numerous inconsistencies.

Three collaborative geological mapping projects were initiated in 2005 by the Manitoba Geological Survey and the University of Waterloo, with financial support from the following mining/exploration companies: Gossan Resources Limited (together with North American Palladium Ltd.), Mustang Minerals Corp and Tantalum Mining Corporation of Canada, Limited (Tanco). The objectives of these projects are to improve the understanding of the stratigraphic, structural and tectonic framework of the BRB and to establish the setting of the various mineral deposits that occur within the belt. This three-year, multidisciplinary project involves targeted bedrock mapping, structural analysis, lithogeochemistry and U-Pb geochronology. The preliminary results of fieldwork undertaken in 2005 were published in Duguet et al. (2005).

Field investigations in 2006 were focused both on the north flank of the BRB and on the south flank of the belt along the Winnipeg River. The objectives were to

- update the lithostratigraphy and the main stratigraphic subdivisions (the Peterson Creek, Bernic Lake and Lamprey Falls formations) and, in particular, establish the contact relationships between the Maskwa Lake Batholith and contiguous BRB supracrustal rocks to the south. Samples for geochemistry and geochronology were collected as part of this investigation.
- investigate the Peterson Creek Shear Zone, particularly in the vicinity of the contact with the Maskwa Lake Batholith. This major shear zone (200–300 m wide) is of potential economic interest since gold has been found in association with sulphide occurrences (Bernatchez, 1994; Murphy and Theyer, 2005).
- establish the regional tectonic setting of the BRB by integrating new geological data along the south flank

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of the BRB with kinematic and structural information. Geochemical and geochronological samples were collected in support of this investigation.

In this report, new data relating to the geology, structure, geochemistry and metamorphism of the Bernic Lake and Peterson Creek formations — as well as geochronological data on the Marijane Lake pluton — are integrated to provide an updated geological and structural framework for the BRB, help establish a revised tectonic history and enhance the understanding of the economic potential of the BRB.

Stratigraphy

Trueman (1980) provided the most comprehensive and detailed description of the lithological subdivisions of the BRB. Six formations were described as follows:

- The Eaglenest Lake Formation is composed of volcaniclastic sediments and minor mafic lavas.
- The Lamprey Falls Formation consists of pillowed basalt with intercalated tuff and iron formation and is in fault contact with the Eaglenest Lake Formation and the Bird River Sill.
- The Peterson Creek Formation contains rhyolite, andesitic and minor basaltic flows, pyroclastic breccia, lapillistone tuff and volcanic sandstone. This formation has been dated (by U-Pb zircon analysis) at 2740 ±4 Ma (Wang, 1993).
- The Bernic Lake Formation is composed predominantly of basalt with subordinate andesite, dacite, rhyolite, iron formation and volcanic sandstone. All of these rocks have been deformed and metamorphosed up to the middle-amphibolite-facies grade. The Bernic Lake Formation is widely intruded by granodiorite, diorite and gabbro plutons; the Tanco pegmatite (2640 ±7 Ma by U-Pb on tantalite; Baadsgaard and Cerny, 1993) occurs within one of the gabbroic plutons.
- The Booster Lake Formation is composed mainly of greywacke-mudstone turbidite. Interbedded conglomerate and iron formation have been observed on the western side of the BRB within this formation (Cerny et al., 1981). This sequence is strongly deformed and a synclinorial structure has been mapped at Booster Lake in the east part of the formation (Gilbert, 2005). This formation has undergone high-temperature–low-pressure metamorphism coeval with the emplacement of the Marijane Lake pluton and the associated pegmatitic granites.
- The Flanders Lake Formation is composed of polymictic conglomerate, which includes pebbles derived from the Bernic Lake Formation and metamorphosed lithic meta-arenite. The Flanders Lake Formation is intruded by the Marijane Lake pluton and is in fault contact with the Peterson Creek, Booster Lake and Bernic Lake formations.

The structural-stratigraphic regional interpretation of Trueman (1980) is based largely on the assumption that the BRB has been deformed in a major synform. The three volcano-sedimentary formations of the BRB (i.e., the Lamprey Falls, Peterson Creek and Bernic Lake formations) were recognized by Trueman on both the north and the south limbs of the major synform. Although the number of units has not been significantly changed, new mapping by the senior author has extensively revised the lithological identity of the stratigraphic subdivisions (Figure GS-16-1). For example, the map unit previously attributed to the Bernic Lake Formation on the north flank of the BRB has been reassigned. Thus, in the west part of the BRB, the Peterson Creek Formation is in direct contact with the Lamprey Falls Formation. South of the Page property (Bird River Sill), a new sedimentary unit has been described (Figure GS-16-1) that does not compare with any rocks previously assigned to the Bernic Lake Formation. The sedimentary subunit may represent a sedimentary cover sequence overlying the Lamprey Falls Formation and the Bird River Sill, with which it is closely associated. Based on this inferred stratigraphic association, the sedimentary subunit has been assigned to the Lamprey Falls Formation. The following descriptions are confined to the Peterson Creek and Lamprey Falls formations because these two formations have undergone the greatest changes as a result of new mapping in 2006.

Lamprey Falls Formation

Lamprey Falls Formation at the north margin of the BRB

The Lamprey Falls Formation at the north margin of the BRB consists mainly of massive to pillowed basalt flows. The formation is a monoclinal south-facing sequence and is pervasively intruded by diabase dikes and gabbro sills associated with sulphide mineralization (*see* Mealin, GS-19, this volume). These mafic dikes occur in both the basalt and the overlying sedimentary subunit as well as the Maskwa Lake Batholith. The northeast to east trend of this diabase-gabbro intrusive complex is parallel to the contacts between the Lamprey Falls Formation, the Peterson Creek Formation and the Bird River Sill. The Lamprey Falls Formation is weakly deformed and metamorphosed at greenschist-facies grade. The Lamprey Falls basalt is similar to a mid-ocean ridge basalt (MORB) and compositionally similar to a modern back-arc basin basalt (BABB; *see* Gilbert, 2005). Geological mapping in 2006 has resulted in extensions of the Lamprey Falls Formation east toward the Maskwa Lake Batholith to the area south of the Page property (Figure GS-16-1). These extensions are based on lithological criteria and are necessarily provisional until they can be confirmed by geochemical data.

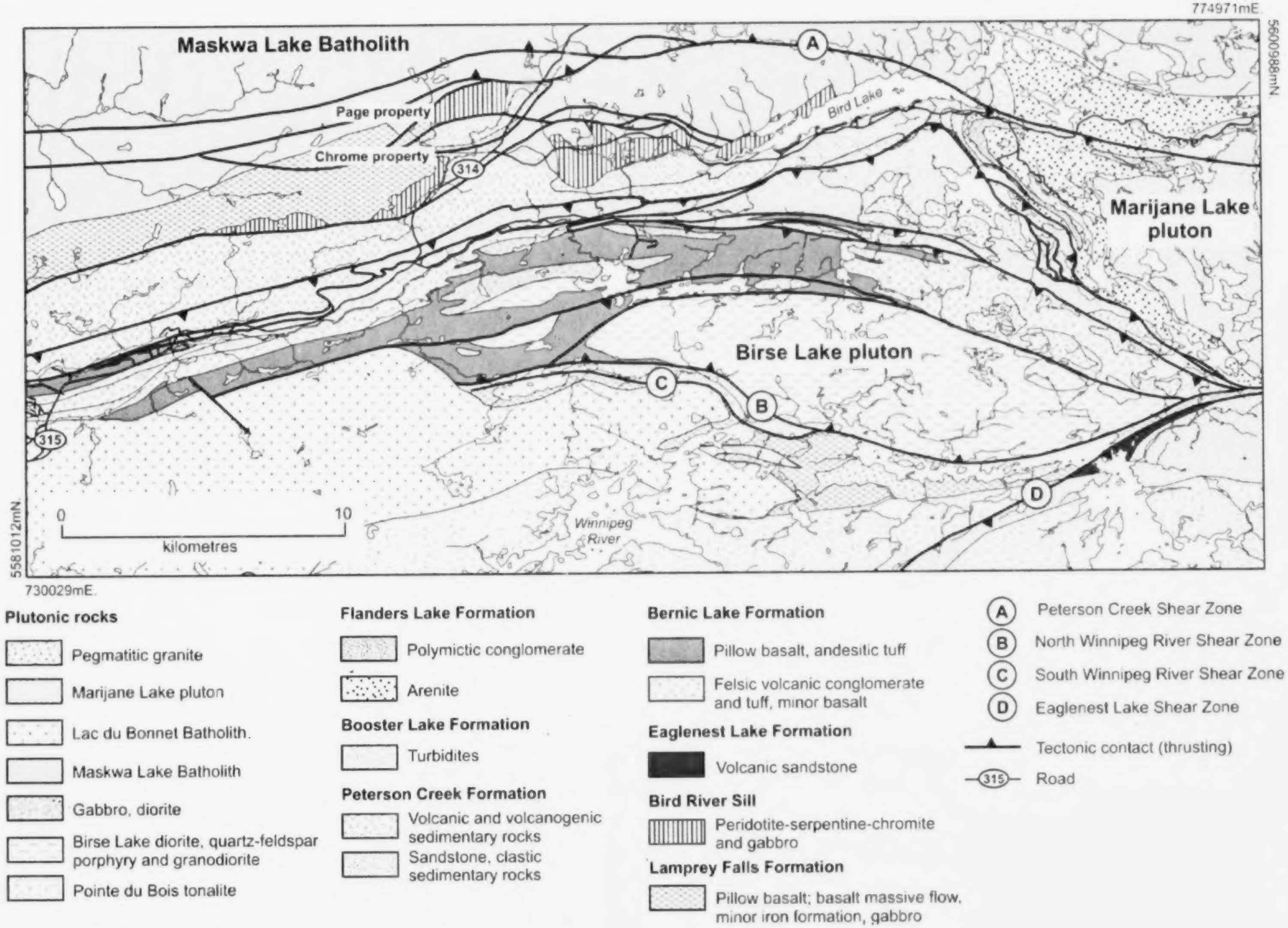
774971mE
5600988mN
730029mE
5581012mN
Maskwa Lake Batholith
Page property
Chrome property
314
Bird Lake
A
Marijane Lake pluton
Birse Lake pluton
C
B
D
315
Winnipeg River
0
10
kilometres
Plutonic rocks
Pegmatitic granite
Marijane Lake pluton
Lac du Bonnet Batholith.
Maskwa Lake Batholith
Gabbro, diorite
Birse Lake diorite, quartz-feldspar porphyry and granodiorite
Pointe du Bois tonalite
Flanders Lake Formation
Polymictic conglomerate
Arenite
Booster Lake Formation
Turbidites
Peterson Creek Formation
Volcanic and volcanogenic sedimentary rocks
Sandstone, clastic sedimentary rocks
Bernic Lake Formation
Pillow basalt, andesitic tuff
Felsic volcanic conglomerate and tuff, minor basalt
Eaglenest Lake Formation
Volcanic sandstone
Bird River Sill
Peridotite-serpentine-chromite and gabbro
Lamprey Falls Formation
Pillow basalt; basalt massive flow, minor iron formation, gabbro
A Peterson Creek Shear Zone
B North Winnipeg River Shear Zone
C South Winnipeg River Shear Zone
D Eaglenest Lake Shear Zone
Tectonic contact (thrusting)
315 Road

Figure GS-16-1: *Simplified geological and structural map of the BRB.*

Sedimentary subunit

The sedimentary subunit within the Lamprey Falls Formation, located in the area south of the Page property, is weakly deformed and folded by northeast- to east-trending upright folds. The folding is inferred from the reversal of stratigraphic-facing direction. No fold hinges were observed in the field. Due to poor exposure and inferred fold structures within the subunit, the following stratigraphic description is only provisional. The base of the sedimentary subunit consists of a heterolithic conglomerate that is discontinuous and appears to be closely associated with the Bird River Sill (*see* Mealin, GS-19, this volume; Gilbert, GS-17, this volume). The conglomerate is composed mainly of well-rounded clasts that constitute up to 90% of the rock (Figure GS-16-2). Clasts range from 0.1 to 1 m in size. The matrix is essentially mafic, composed chiefly of hornblende. Clast types include basalt and gabbro pebbles (predominantly derived from the Lamprey Falls Formation and the Bird River Sill), felsic volcanic rocks and quartz pebbles. The conglomerate appears to be locally interbedded with massive basalt. It is uncertain whether these rock units are conformable or structurally intercalated.

The basal conglomerate of the sedimentary subunit is overlain by a central siltstone-greywacke-conglomerate member. Graded bedding in the central member is abundant and locally indicates opposing top directions, which suggests the sequence is folded. The conglomerate contains well-rounded clasts that include centimetre-scale quartz, feldspar and possible rhyolite. Some parts of the central member consist of massive volcaniclastic sandstone with blue quartz grains. The sandstone could have been derived from resedimented felsic volcanic flows. In some respects, the central member of the sedimentary subunit is comparable to turbidites of the Booster Lake Formation.

The upper member of this sedimentary subunit consists of white laminated chert, approximately 20 to 30 m in width.

The sedimentary subunit is interpreted to be unconformable with the underlying Lamprey Falls basalt and the Bird River Sill. No contacts are exposed in the field and there is no angular unconformity evident between these map units. The basal contact of the conglomerate is interpreted as disconformable.

Lamprey Falls Formation at the south margin of the BRB (Winnipeg River area)

A thick sequence of basalt outcrops along the shores of the Winnipeg River in the area west of Eaglenest Lake. Pillows are widespread in the mafic flows and are reliable north-facing top indicators. Sporadic south-facing flows indicate that the mafic volcanic section is folded. Sulphide mineralization, locally associated with oxide-facies iron formation, occurs at two stratigraphic levels within the basaltic sequence (*see* Gilbert, GS-17, this volume). In contrast to the Lamprey Falls Formation at the north margin of the BRB, the basalt along the Winnipeg River is strongly deformed and metamorphosed at a relatively higher metamorphic grade, as indicated by garnet-bearing assemblages that are common within this basalt. The basalt is in fault contact with felsic volcanic rocks and the Birse Lake pluton to the north, as well as the sediments of the Eaglenest Lake Formation and Pointe du Bois tonalite pluton to the south. The basalt is intruded by the post-tectonic Lac du Bonnet Batholith that occurs immediately west of the Lamprey Falls Formation. The Lamprey Falls basalt is widely intruded by abundant gabbroic sills and quartz-feldspar porphyry intrusions associated with the Birse Lake pluton to the north. The gabbroic dikes are assumed to postdate the quartz-feldspar porphyry because the former are slightly boudinaged, whereas the latter is strongly mylonitized.

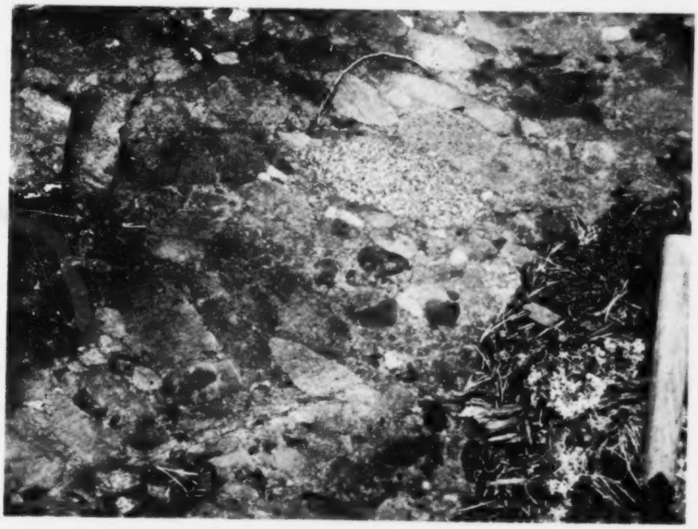

Figure GS-16-2: *Polymictic conglomerate composed of mafic and minor felsic cobbles (south of the Page property). The mafic pebbles are from the Lamprey Falls basalt and the Bird River Sill gabbro (hammer for scale).*

Peterson Creek Formation

Stratigraphy

The following stratigraphic description is based on the part of the Peterson Creek Formation north of the Booster Lake Formation, west of the former Maskwa-Dumbarton mines and east of Provincial Road 314. The bedrock exposure in this area is irregularly distributed and the rocks are commonly deformed. Thus, a detailed and comprehensive stratigraphic investigation has not been possible.

Within the mapped area, the Peterson Creek Formation consists of two members: lower and upper. The lower member is composed of basaltic to dacitic massive flows and their tuffaceous and pyroclastic equivalents. This member is well exposed in an anticlinal fold structure in the central part of the area. Massive flows in the southeastern part of the area are intercalated with tuffaceous equivalent units of similar composition and with minor rhyolitic layers. Crystal tuffs range from lapillistone tuff with decimetre-scale clasts to ash-flow tuff with millimetre-scale detritus. The matrix has dark grey to black weathering and contains abundant hornblende. A thick, 200 to 300 m layer of mafic lapillistone and flow breccia is intercalated with basalt in the central part of this member. The rocks have been metamorphosed at upper-greenschist- to lower-amphibolite-facies grade. The mineral assemblage in the andesite-dacite flows is garnet+hornblende+biotite+epidote+plagiclase ±carbonate and the assemblage in basaltic rock consists of hornblende+quartz+plagioclase±epidote. The metamorphic grade of these volcanic rocks is very similar to that of rocks in the Bernic Lake Formation south of the Booster Lake Formation (Figure GS-16-1).

The upper member of the Peterson Creek Formation in the area mapped consists of two subunits. The first subunit, interpreted as being older, consists of thinly bedded, aphyric to quartz-phyric rhyolite and tuff. A sericite-rich, white to grey weathering surface is characteristic of this subunit. The inferred younger subunit to the north consists of massive to weakly stratified, rhyolitic to dacitic lapilli tuff and rhyolite. The tuff contains plagioclase-phyric pumice clasts within a dark grey matrix. In the east part of the mapped area, well-rounded blue quartz is an additional component in the well-bedded, tuffaceous deposit, which also contains detrital plagioclase and is classified as volcaniclastic sandstone.

Geochemistry

Eight samples (six from the Peterson Creek Formation and two from the Bernic Lake Formation) were analysed for major, trace and rare earth elements. The samples range from andesitic basalt to rhyolite in composition.

Plots of felsic volcanic rocks (dacite to rhyolite) in the primitive-mantle–normalized incompatible elements diagram are characterized by strongly enriched light rare earth elements (LREE), strong negative Nb and moderate to strong negative Eu anomalies, as well as moderate to very prominent negative Ti anomalies. Heavy rare earth elements (HREE) are weakly fractionated and strongly enriched (sample 2321A; Figure GS-16-3).

Plots of mafic and intermediate volcanic rocks (47–65 wt. % SiO_2; 0.011–0.022 Zr/TiO_2) display profiles similar to those of felsic volcanic rocks in primitive-mantle–normalized extended diagrams. The mafic to intermediate rocks are characterized by enriched and fractionated LREE, moderate negative Nb anomalies and weakly fractionated and strongly enriched in HREE (Figure GS-16-3).

All eight samples plot in the arc or continental crust field in the Th/Yb vs. Ta/Yb diagram.

Structural geology and deformation history

Available data

Details of the structural geology in the north part of the BRB are described in Duguet et al. (2005). This section provides a brief update of the tectonic history and a reinterpretation of the kinematic and structural data.

The belt was affected at first by vertical movements with south-side-up shearing in the study area (Duguet et al., 2005). This D_1 event thrust the Bernic Lake Formation from the south onto Booster Lake Formation rocks to the north, which in turn was structurally superimposed on the Peterson Creek and Flanders Lake formations. An interesting feature of this tectonic event is the juxtaposition of units metamorphosed under amphibolite-facies conditions (i.e., the Bernic Lake Formation) upon units of a lower metamorphic grade (i.e., turbidites of the Booster Lake Formation). This characteristic strongly suggests an initial low-angle thrust-type event and the subsequent steepening of the units prior to strike-slip; moreover, this idea has been strengthened by some new geochronological data, which seem to show that the Booster Lake Formation is slightly older than the Flanders Lake Formation.

The D_1 tectonic event evolved from initial thrusting into a transpressive event with a significant strike-slip movement, although the principal component of the movement was vertical. This history is particularly well documented in the Booster Lake area, where dextral shearing is included in the same fabric in which the south-side-up movement is documented. The direction of strike-slip movement varies depending on the locality. Dextral shearing is clearly associated with a southeast- to east-trending fault in the Booster Lake area. On the other hand, sinistral strike-slip movements in the Booster Lake Formation west of the Tanco mine road, and also at the northeast edge of the Birse Lake pluton, are associated with northeast-trending faults. This strike-slip event is

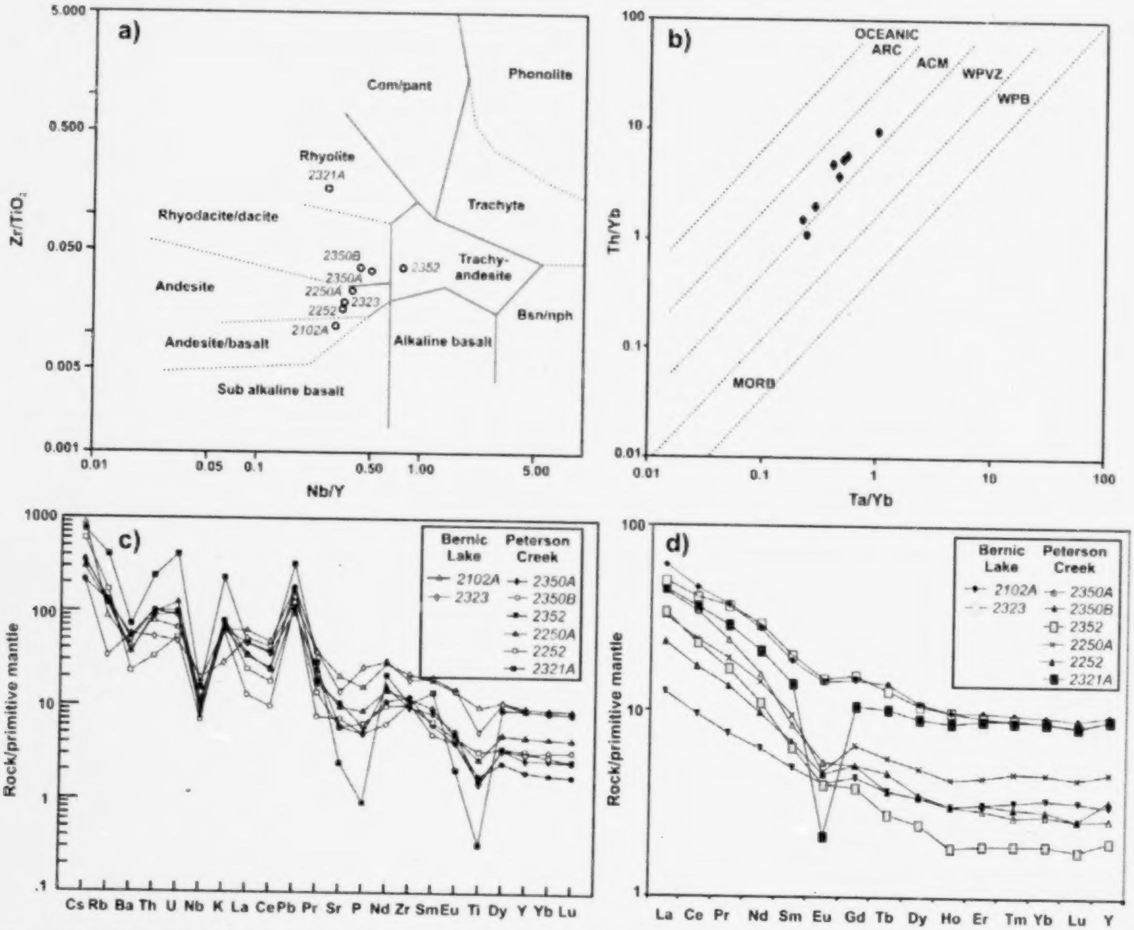

***Figure GS-16-3:** Geochemical discrimination diagrams for samples of felsic volcanic rock in the Peterson Creek and Bernic Lake formations: **a)** Nb/Y vs. Zr/TiO$_2$ (after Winchester and Floyd, 1977; abbreviations: Bsn, basanite; nph, nepheline); **b)** revised Ta/Yb vs. Th/Yb discriminant diagram (after Pearce, 1983; abbreviations: ACM, active continental margin; WPVZ, within plate volcanic zones; WPB, within plate basalts; MORB, mid-ocean ridge basalt); **c)** primitive-mantle–normalized (Sun and McDonough, 1989) extended-element diagram for samples of mafic and felsic metavolcanic rocks in the Peterson Creek and Bernic Lake formations; **d)** primitive-mantle–normalized rare earth element diagram for samples of mafic and felsic metavolcanic rocks in the Peterson Creek and Bernic Lake formations.*

probably associated with the upright folding that affects all map units. The upright folds are well documented in the east part of the BRB in the Booster Lake and Flanders Lake formations (Gilbert, 2005; Duguet et al., 2005). The trend of major folds is variable from area to area (east in the central part, southeast in the eastern part and northeast in the western part) but these folds are invariably parallel to the tectonic contacts. During the D$_1$ event, the Marijane Lake pluton was emplaced in the Flanders Lake Formation. The synkinematic emplacement of this granite resulted in magmatic foliation folded by the southeast-trending upright folds in this area (Figure GS-16-1). Furthermore, some dikes associated with the granitoid pluton intrude the Peterson Creek Shear Zone in this area and display an asymmetric dextral boudinage with a vertical south-side-up component of movement. The Marijane Lake pluton has been dated at 2631 ±4 Ma by U-Pb on monazite (D. Davies, pers comm, 2006). The last tectonic movements resulted in upright folds and dragfolds that crosscut all rock types and reworked some tectonic contacts. These folds seem to be associated with the onset of some movements along major shear zones, which appear to postdate the folds. A good example is situated just west of the former Maskwa-Dumbarton mine, where a hectometre-scale northeast-trending fold deforms both the Peterson Creek and Booster Lake formations. West of Provincial Road 314, southeast-trending upright folds also deform the Peterson Creek and Booster Lake formations. These late structures are interpreted as en échelon folds during the last sinistral movement along the shear zone.

Peterson Creek Shear Zone (PCSZ)

The Peterson Creek Shear Zone (PCSZ) is a conspicuous structural feature that plays a major role in the tectonic history of the north part of the BRB. This shear zone crosscuts all the geological units of the area, namely the Lamprey Falls Formation, the Maskwa Lake Batholith, the Flanders Lake Formation and the Marijane Lake pluton. The greater part of the PCSZ trends east through the Maskwa Lake Batholith. Toward the east, the trend of the PCSZ changes to the southeast. Fieldwork this year focused on the west part of the shear zone where it intersects the Bird River Sill and the Lamprey Falls and Peterson Creek formations. The east-trending shear zone in this area is estimated to be 200 m wide. All the facies of Maskwa Lake Batholith are strongly deformed and locally altered to ultramylonite (Figure GS-16-4). This deformed facies has rarely been observed due to the relatively sparse outcrop. In contrast to the shearing in the east part of the PCSZ, kinematic criteria in the west part of the zone indicate a top-to-the-south shearing associated with a dextral component of movement.

Two sets of several other small ductile faults arise directly from the PCSZ. The first set is oriented southeast to east and is characterized by dextral displacement, whereas the second set, oriented northeast, is associated with sinistral shearing (Figures GS-16-5 and GS-16-6). Horizontal displacement along of these faults is invariably subordinate to the amount of vertical movement. Available shear criteria on the vertical X-Z planes indicate a north-side-up shearing. The principal characteristic of these shear zones is to present an important curvature (Figure GS-16-7). The same fault can have both previously described directions associated with their kinematics. Thus, these faults delineate kinematic domains or boudins almost free of internal deformation (Figures GS-16-4 and GS-16-7). Deformation takes place at the

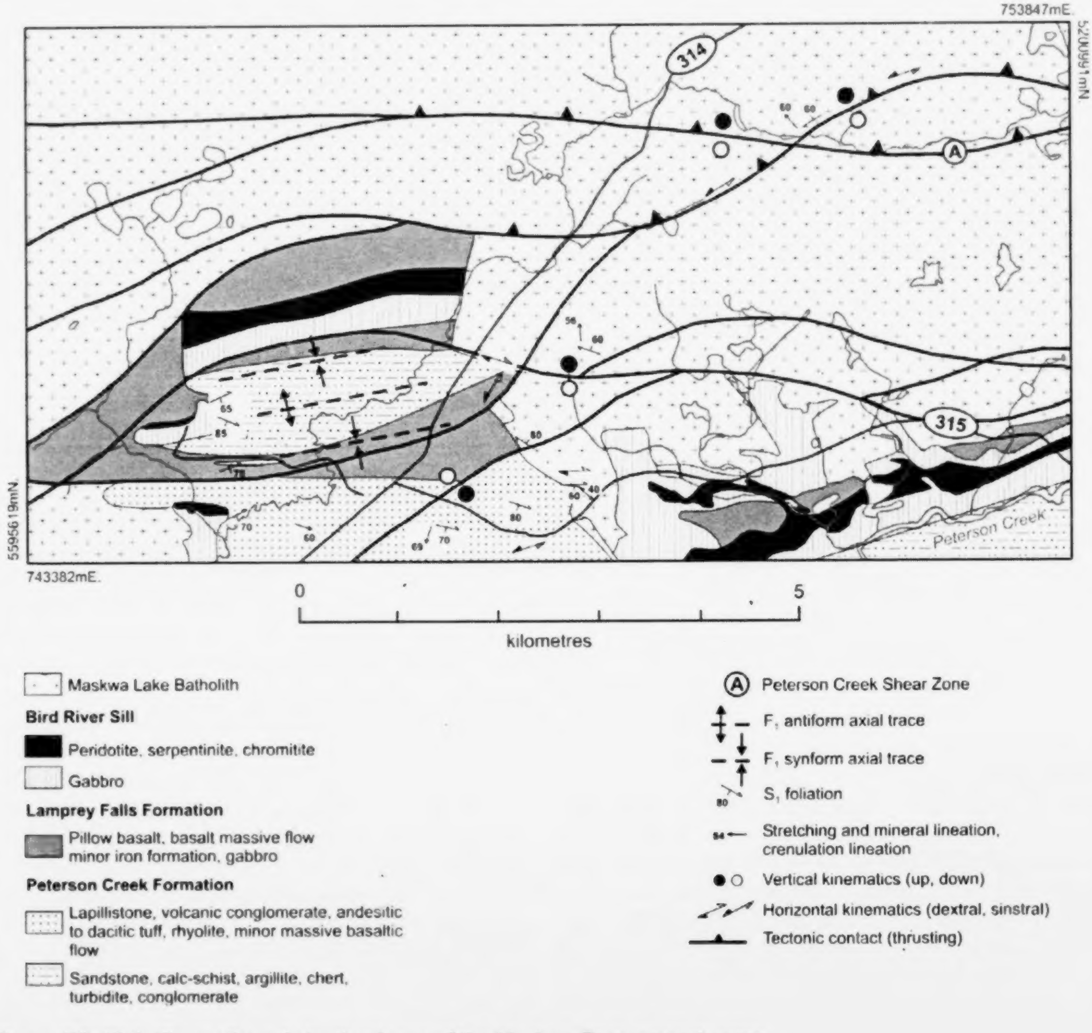
753847mE
5520099mN
314
A
315
Peterson Creek
5595619mN
743382mE
0
5
kilometres
Maskwa Lake Batholith
Bird River Sill
Peridotite, serpentinite, chromitite
Gabbro
Lamprey Falls Formation
Pillow basalt, basalt massive flow minor iron formation, gabbro
Peterson Creek Formation
Lapillistone, volcanic conglomerate, andesitic to dacitic tuff, rhyolite, minor massive basaltic flow
Sandstone, calc-schist, argillite, chert, turbidite, conglomerate
Peterson Creek Shear Zone
F1 antiform axial trace
F1 synform axial trace
S1 foliation
Stretching and mineral lineation, crenulation lineation
Vertical kinematics (up, down)
Horizontal kinematics (dextral, sinstral)
Tectonic contact (thrusting)

Figure GS-16-4: *Kinematic and structural map of the Maskwa-Page property area.*

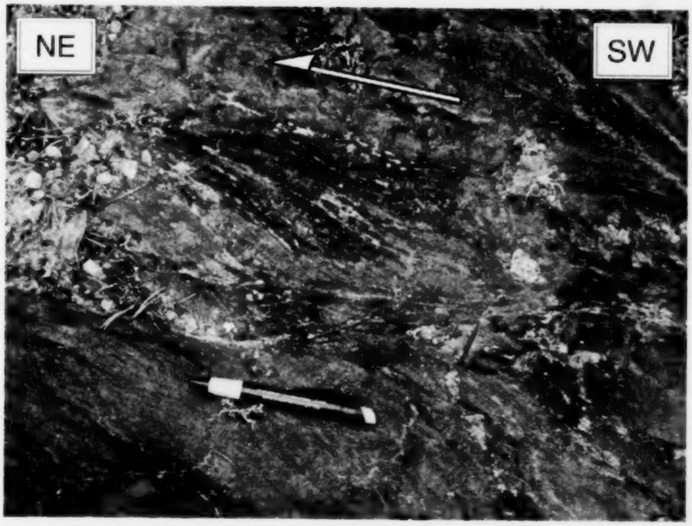

Figure GS-16-5: *Shear bands in tuff with a sinistral shear sense (Ore Fault deposit). The shear zone is oriented to the northeast (pencil for scale).*

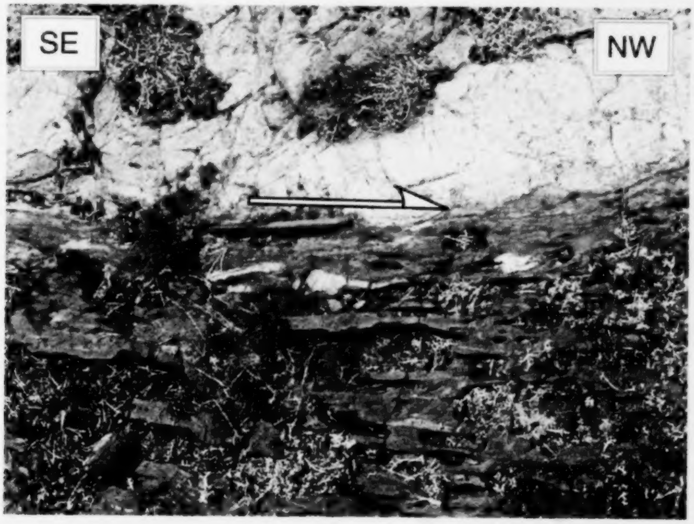

Figure GS-16-6: *Asymmetric boudin of quartz pod with a dextral shear sense (Ore Fault deposit). The shear zone is oriented southeast and affects only the mafic dike. The hostrock represented by the Maskwa Lake Batholith is free of deformation (pencil for scale).*

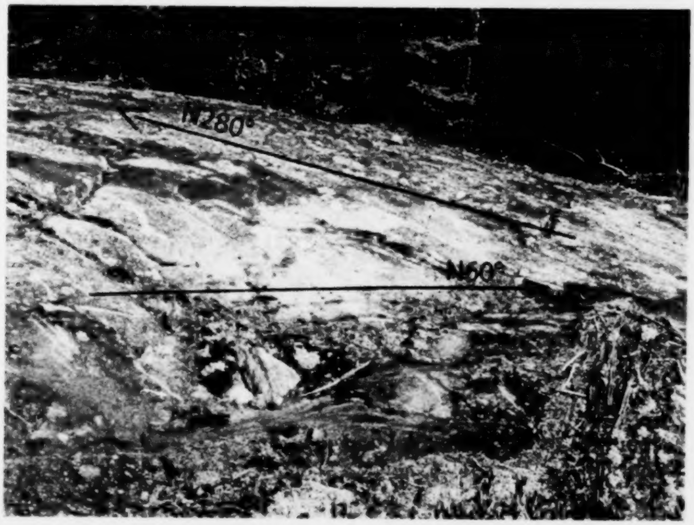

Figure GS-16-7: *Conjugate sets of ductile shear zones in the Maskwa Lake Batholith.*

boundary of the boudin and often at the contact between different rock types. For example, numerous mafic dikes within the Maskwa Lake Batholith are deformed, whereas the granite itself is almost free of deformation. This structural pattern is observed at both small (outcrop) and large (map) scales, and is particularly well defined in the Maskwa Lake Batholith; it is also applied to rocks of the Bird River Sill at the Page property and the Lamprey Falls Formation. Some of these faults apparently served as conduits for the distribution and dispersion of base-metal sulphide. Examples of such mineralization include the Ore Fault property (Murphy and Theyer, 2005) and a sulphide mineral occurrence located just south of the PCSZ and east of Provincial Road 314 (Bernatchez, 1994).

Winnipeg River area

In the Winnipeg River area, all geological units display a strong deformation fabric represented by a southeast- to east-trending foliation in the western and central parts and northeast-trending foliation in the eastern part (Figure GS-16-8). The subvertical- to vertical-dipping foliation is inclined alternatively north or south. This foliation commonly bears a prominent stretching and mineral lineation presenting a steep plunge. This foliation seems to be unique in the investigated area. The fabric is also parallel to the original stratigraphic bedding represented by pillowed mafic volcanic flows and sedimentary strata, and is locally folded by upright folds with axes plunging moderately westward.

The Winnipeg River area contains two major shear zones. Three geological units are delineated by faults in the north part of the Winnipeg River area: the Birse Lake pluton to the north, felsic volcanic rock (interpreted as a part of the Peterson Creek Formation) in the centre and basaltic flows assigned to the Lamprey Falls Formation to the south. The contact between the Birse Lake granite and the Lamprey Falls basalt is strongly deformed and shear criteria (such as sigma-type porphyroclasts and garnet porphyroblasts) as well as shear bands indicate

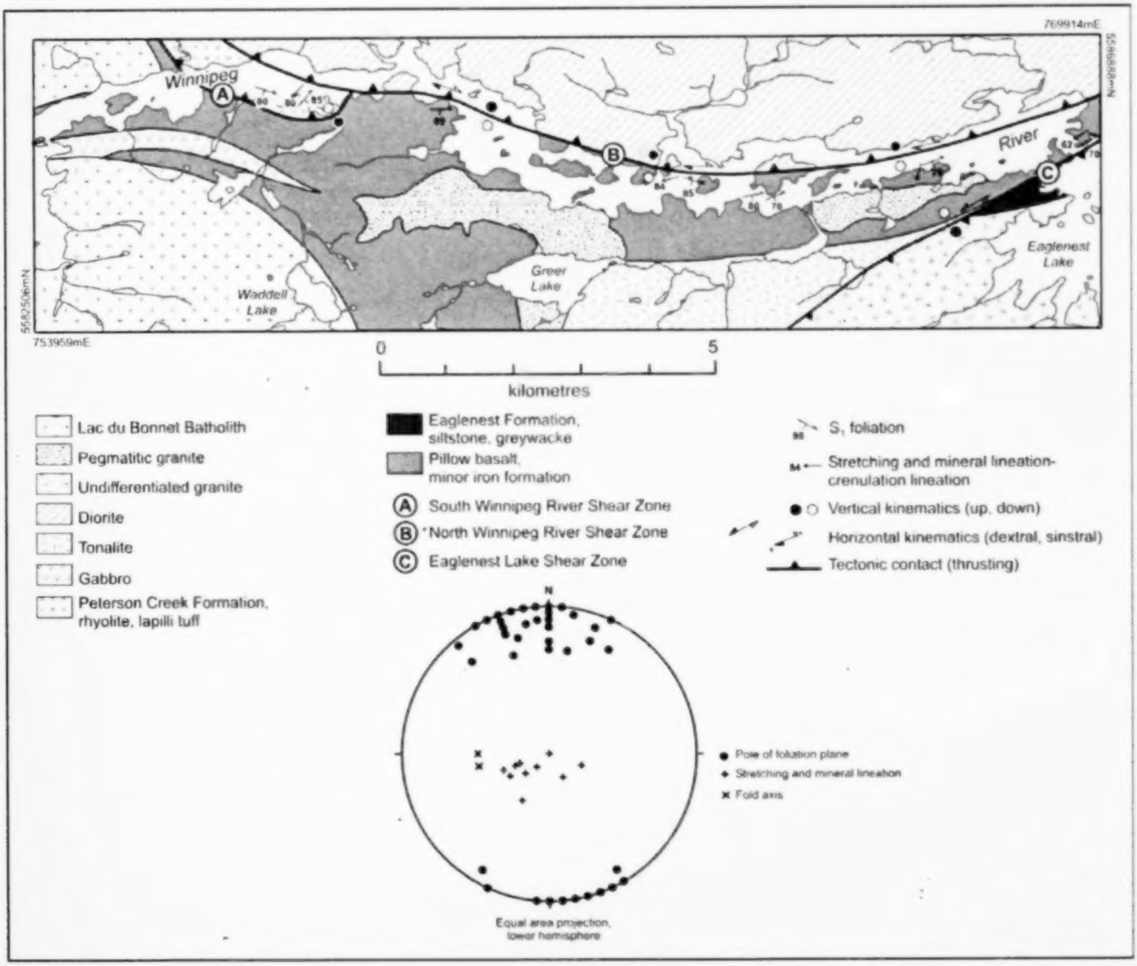
769914mE
5586688mN
5582506mN
753959mE
Winnipeg
River
A
B
C
Greer Lake
Waddell Lake
Eaglenest Lake
0
5
kilometres
Lac du Bonnet Batholith
Pegmatitic granite
Undifferentiated granite
Diorite
Tonalite
Gabbro
Peterson Creek Formation, rhyolite, lapilli tuff
Eaglenest Formation, siltstone, greywacke
Pillow basalt, minor iron formation
Ⓐ South Winnipeg River Shear Zone
Ⓑ North Winnipeg River Shear Zone
Ⓒ Eaglenest Lake Shear Zone
S_1 foliation
Stretching and mineral lineation-crenulation lineation
● ○ Vertical kinematics (up, down)
Horizontal kinematics (dextral, sinstral)
Tectonic contact (thrusting)
N
● Pole of foliation plane
+ Stretching and mineral lineation
× Fold axis
Equal area projection, lower hemisphere

Figure GS-16-8: Structural and kinematic map of the Winnipeg River area.

a consistent north-side-up direction of shearing with a dextral component of movement along the contact (Figures GS-16-9 and -10). The contact between basalt and pegmatitic granite at the south shore of the Winnipeg River is also affected by this shearing event, which resulted in the formation of dextral shear bands. The fault zone at that locality is identified as the North Winnipeg River Shear Zone (NWRSH). Farther west, the contact between felsic and mafic volcanic rocks of the Peterson Creek and Lamprey Falls formations, respectively, is identified as the South Winnipeg River Shear Zone (SWRSH). This fault is strongly deflected at the junction with NWRSH and adopts a southeast to south trend. The deflection is probably due to folding at a relatively late stage in the deformation history. Shear criteria at one locality in this area indicate a south-side-up direction of shearing.

In the south part of the Winnipeg River area, a major northeast-trending shear zone occurs between the Lamprey Falls and Eaglenest Lake formations. This shear zone, identified as the Eaglenest Lake Shear Zone (ELSZ), is 300 to 400 m wide and associated with a conspicuous topographic lineament. The ELSZ is characterized by a sinistral horizontal offset associated with south-side-up shearing. Shear criteria within the zone consist of asymmetrically boudinaged granitic pods and dikes (Figures GS-16-11 and -12). The ELSZ is intruded to the south by pink-white granite that is petrographically similar to the Marijane Lake pluton. This granite displays a conspicuous magmatic foliation defined by the alignment of K-feldspar and by mafic enclaves, which are oriented parallel to the shear zone boundaries (Figure GS-16-13). These features suggest that the emplacement of the granite was coeval with the onset of shearing of the ELSZ.

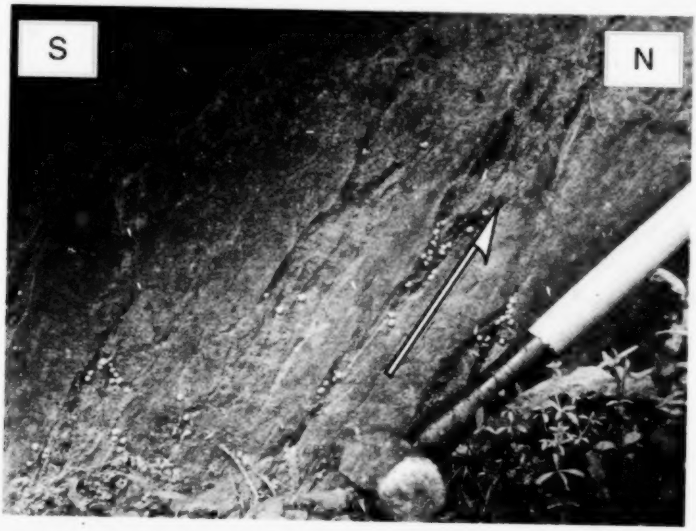

Figure GS-16-9: *Asymmetric boudinage of basalt, giving a north-side-up shearing (hammer for scale).*

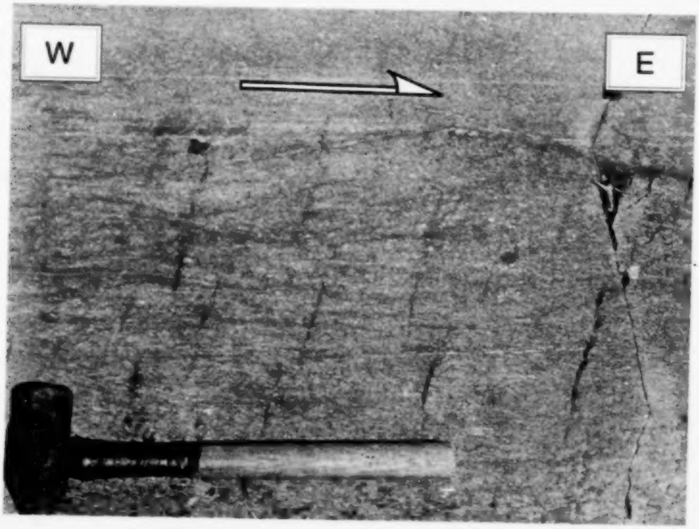

Figure GS-16-10: *Shear bands in the Birse Lake pluton showing dextral shearing (horizontal plane; hammer for scale).*

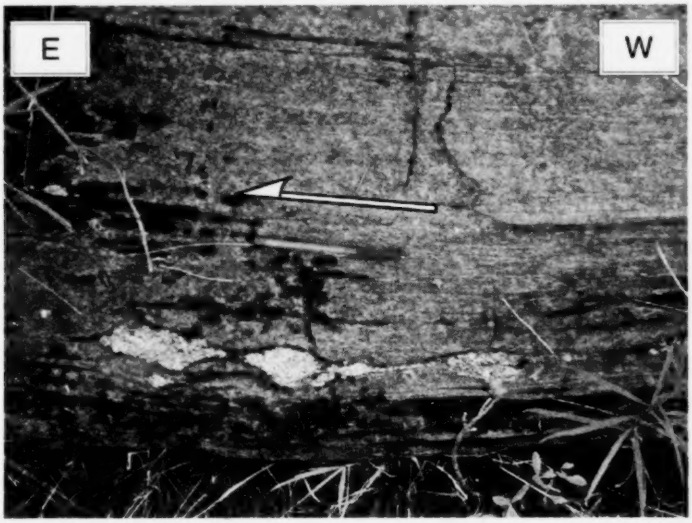

Figure GS-16-11: *Asymmetric boudinage of granitic pods in Eaglenest Lake Formation, indicating sinistral shearing (horizontal plane; pencil for scale).*

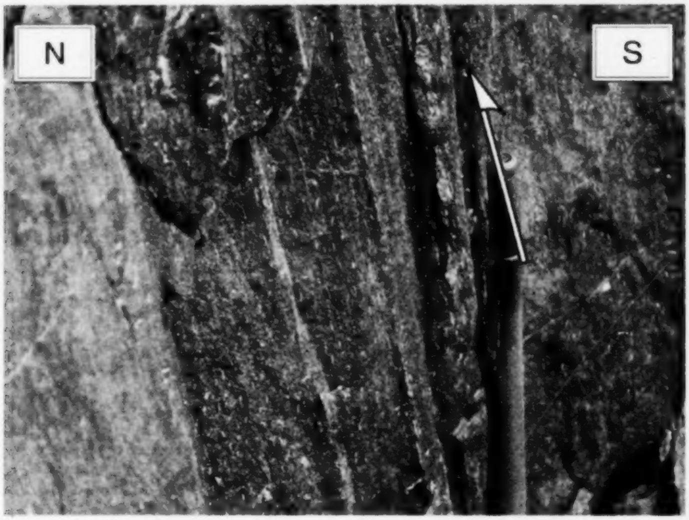

Figure GS-16-12: *Asymmetric boudinage of granitic pods in Eaglenest Lake turbidite giving a south-side-up shearing (vertical plane, contact between the Lamprey Falls Formation and the Eaglenest Lake Formation; pencil for scale).*

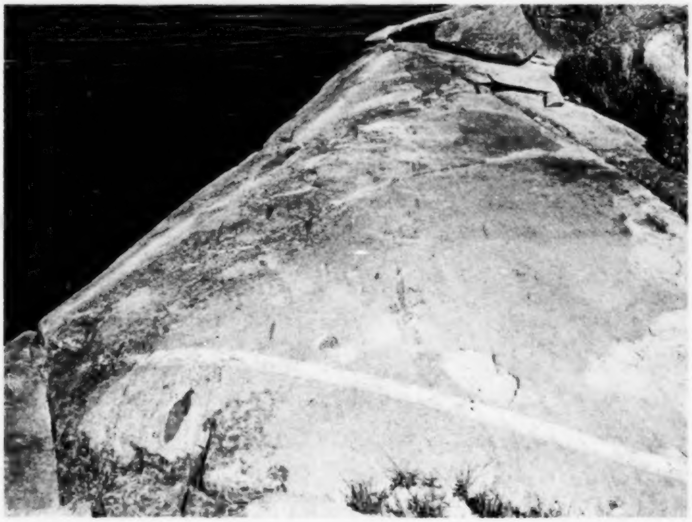

Figure GS-16-13: *Magmatic foliation in the granite intruding the Eaglenest Lake Shear Zone. Note the strong orientation of mafic enclaves.*

Discussion

Field investigations in 2005, complemented by data collected in 2006, have provided a basis for the following observations regarding the tectonic history of the BRB:

- All shear criteria that were observed have indicated that the central part of the BRB is tectonically uplifted relative to the margins. All documented faults are interpreted as high-angle reverse faults with only a horizontal offset.
- The BRB is sigmoidal in shape.
- Many of the shear zones that were mapped are part of a regional anastomosing network. The faults have various orientations in response to antithetic shearing in the horizontal plane.
- The same tectonic contact can change the orientation of its principal stress ellipsoid along strike.
- Two parallel faults can be characterized by opposite directions of offset. This feature is particularly well illustrated in the Winnipeg River area.
- These observations are consistent with the inferred model for the BRB as a pop-up structure assumed to have developed during a progressive single transpressive event. The last movements in the north part of the BRB are coeval with the emplacement of the 2631 Ma Marijane Lake pluton.

Preliminary results on metamorphic history

Two rock samples from the Peterson Creek Formation in the area south of Bird Lake and one rock sample from the Bernic Lake Formation close to the contact with the Booster Lake Formation were used to investigate metamorphic mineral assemblages. Electron microprobe analyses were undertaken on selected metamorphic minerals and examined for petrographic textures. The mineral assemblage of the two samples from the Peterson Creek Formation (2350A and 352) is as follows: garnet+blue-green amphibole+biotite+plagioclase +quartz±epidote. A third sample from the Bernic Lake Formation (2102A) consists of garnet biotite+green hornblende+ilmenite+plagioclase+quartz. Thermobarometric data (performed by the THERMOCALC™ software) are summarized in Table GS-16-1. The pressure-temperature conditions for the Peterson Creek Formation are estimated to be 550°C and 5 kbar. Data from sample 2102A indicate that the pressure for the Bernic Lake Formation is lower (3–4 kbar), assuming temperatures similar to those of the Peterson Creek Formation. The pressure of 3 kbar was calculated from analyses of rim minerals and 4 kbar was indicated by core mineral analysis. The estimated pressure conditions, together with petrographic data, indicate that garnet breakdown had been initiated. These features and the estimated 3 to 4 kbar pressure conditions are consistent with retrogressive metamorphism during the D_1 top-to-the-north event in the Bernic Lake Formation.

Economic considerations

The BRB has been extensively explored for ore deposits since 1920, when (Ni-Cu) sulphide deposits were discovered in the Cat Creek–Maskwa River area (McCann, 1921). At present, economic interest is focused on mineralization allied to three known ore deposits: the Tanco rare-element pegmatite, the Maskwa Fe-Ni-Cu-platinum group element (PGE) deposit and the Dumbarton Ni-Cu-Zn-PGE deposit.

The Tanco mine at Bernic Lake has produced tantalum, cesium and lithium since 1969. The Maskwa and Dumbarton deposits were mined from 1974 to 1976 and from 1969 to 1973, respectively; renewed production at Maskwa is planned as a result of the recent discovery of additional ore reserves (Mustang Minerals Corp., 2005). In the area north of Bernic Lake, Ni-Cu-PGE mineralization is spatially associated with the mafic-ultramafic Bird River Sill.

At the present time, the BRB is being extensively explored by the Tantalum Mining Corporation of Canada Limited (for rare element-bearing pegmatite deposits), and by Gossan Resources Limited and Mustang Minerals Corp. (for Ni-Cu-Zn-PGE). The geological setting of the different ore deposit types remains poorly understood. Mapping, structural and kinematic analyses, and geochronological investigations are necessary in order to better understand both the evolution of the BRB and the setting of the various ore deposit types, and will aid in supporting exploration programs that currently are underway in the area.

Acknowledgments

The Manitoba Geological Survey, the University of Waterloo, Gossan Resources Limited, North American Palladium, Mustang Minerals Corp. and the Tantalum Mining Corporation of Canada Limited (Tanco) have generously supplied funding for this project. P. Kremer and C. Mealin are gratefully acknowledged for sharing their ideas on the BRB. Students L. Osadchuk, K. Louis and B. Foster provided voluntary assistance in the field throughout the summer. The manuscript was considerably improved by thoughtful comments from T. Corkery and P. Gilbert. The senior author is also grateful to G. Turcan and D. Deason from the Kendall Point Lodge for providing accommodation.

Table GS-16-1: Thermobarometric data for samples 2102A, 2350A and 2352A, Peterson Creek Formation (abbreviations: ab, albite; alm, almandine; an, anorthite; ann, annite; cor, correlation factor; cz, clinozoisite; east, eastonite; ep, epidote; fact, ferroactinolite; fep, ferroepidote; gl, glaucophane; gr, grossular; P, pressure; parg, paragonite; phl, phlogopite; py, pyrite; q, quartz; sd, standard deviation; sigfit, significant fit; T, temperature; tr, tremolite; ts, tschermakite).

Sample 2102A:

T = 520°C, sd = 43,

P = 3.2 kbar, sd = 1.2, cor = 0.594, sigfit = 1.05

Independent set of reactions

1) 2py + 4gr + 3ts + 12q = 3tr + 12an
2) 6tr + 21an = 10py + 11gr + 27q + $6H_2O$
3) 6fact + 21an = 11gr + 10alm + 27q + $6H_2O$
4) 3tr + 6parg + 18an = 4py + 8gr + 6ts + 3gl
5) py + ann = alm + phl
6) 3tr + 3ts + 6parg + 18ab = 4py + 8gr + 12gl
7) 6parg + 12phl + 18an = 4py + 8gr + 3tr + 3gl + 12east

Sample 2102A (core minerals):

T = 555°C, sd = 44,

P = 4.3 kbar, sd = 1.3, cor = 0.613, sigfit = 0.89

Independent set of reactions

1) 2py + 4gr + 3ts + 12q = 3tr + 12an
2) 6tr + 21an = 10py + 11gr + 27q + $6H_2O$
3) 6fact + 21an = 11gr + 10alm + 27q + $6H_2O$
4) 3tr + 6parg + 18an = 4py + 8gr + 6ts + 3gl
5) py + ann = alm + phl
6) 3tr + 3ts + 6parg + 18ab = 4py + 8gr + 12gl
7) 6parg + 12phl + 18an = 4py + 8gr + 3tr + 3gl + 12east

Sample 2350A:

T = 557°C, sd = 55,

P = 5.1 kbar, sd = 1.1, cor = 0.610, sigfit = 0.76

Independent set of reactions

1) 2py + 4gr + 3ts + 12q = 3tr + 12an
2) 6tr + 21an = 10py + 11gr + 27q + $6H_2O$
3) 6fact + 21an = 11gr + 10alm + 27q + $6H_2O$
4) 3tr + 6parg + 18an = 4py + 8gr + 6ts + 3gl
5) py + ann = alm + phl
6) 3tr + 3ts + 6parg + 18ab = 4py + 8gr + 12gl
7) 6parg + 12phl + 18an = 4py + 8gr + 3tr + 3gl + 12east

Sample 2352A:

T = 500°C, sd = 38,

P = 5.2 kbar, sd = 1.0, cor = 0.920, sigfit = 0.96

Independent set of reactions

1) 10py + 3tr + 24cz = 4gr + 15ts + 12an
2) 2py + 4gr + 3ts + 12q = 3tr + 12an
3) 19ts = 14py + 3tr + 16cz + $8H_2O$
4) 4gr + 5alm + 6cz + 15q = 3fact + 18an
5) 4gr + 5alm + 12ep + 15q = 3fact + 18an + 6fep
6) py + ann = alm + phl
7) 4py + 8gr + 9ts + 6ab = 3tr + 6parg + 24an
8) 5py + 15phl + 12cz = 2gr + 6tr + 15east + 6an

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GS-17 Geological investigations in the Bird River area, southeastern Manitoba (parts of NTS 52L5N and 6)

by H.P. Gilbert

Gilbert, H.P. 2006: Geological investigations in the Bird River area, southeastern Manitoba (parts of NTS 52L5N and 6); *in* Report of Activities 2006, Manitoba Science, Technology, Energy and Mines, Manitoba Geological Survey, p. 184–205.

Summary

A regional mapping project in the Neoarchean Bird River Belt (BRB) of southeastern Manitoba was initiated by the Manitoba Geological Survey in 2005. Both reconnaissance mapping and localized, more detailed work in the east and west parts of the greenstone belt were carried out. Mapping was continued in the east and central parts of the belt in 2006, with a focus on stratigraphy and volcanic geochemistry.

The north margin of the belt consists of basalt (Lamprey Falls Formation) akin to modern back-arc basin basalt (BABB). The basalt is structurally overlain by a south-facing, arc-type volcanosedimentary sequence that postdates the BABB-type sequence. New U-Pb zircon dates show that turbidites (Booster Lake Formation) and fluvial-alluvial deposits (Flanders Lake Formation), which are largely confined to the east part of the greenstone belt, postdate the arc-type rocks by approximately 30 m.y. The fault-bounded Booster Lake Formation extends through the central part of the BRB, dividing it into north and south panels. The south panel consists mainly of felsic volcanic fragmental rocks and north-facing basaltic units of inferred arc-type composition.

A subsidiary supracrustal belt extends along the Winnipeg River south of the 'main' greenstone belt in the Bird River area. The mid-ocean-ridge basalt (MORB)–like basaltic rocks predominant in the Winnipeg River area are compositionally similar to the basalt formation at the north margin of the greenstone belt; these two components are correlated stratigraphically and named accordingly as the Lamprey Falls Formation.

Sporadic zones of mineralization occur within the arc-type volcanosedimentary sequence in the BRB, and prominent mineralization also occurs within the Lamprey Falls Formation. North of Bird River, the latter formation locally contains Cr–platinum group element (PGE) and minor base-metal sulphide mineralization in gabbroic sills assumed to be related to the mafic-ultramafic Bird River Sill. Lamprey Falls Formation basalt on the south shore of the Winnipeg River contains a conspicuous 65 m wide zone of pyrite-pyrrhotite-chalcopyrite mineralization associated with a volcanic exhalitive unit of chert and oxide-facies iron formation.

Introduction

Geological investigations were initiated in 2005 in the Neoarchean BRB of southeastern Manitoba (Figure GS-17-1). Mapping and thematic geological studies were undertaken jointly by the Manitoba Geological Survey (MGS) and the University of Waterloo, supported by funding from the Natural Sciences and Engineering Research Council of Canada (NSERC) and financial support provided by Gossan Resources Limited, North American Palladium Ltd., Mustang Minerals Corp. and Tantalum Mining Corporation of Canada Ltd. (Tanco). The purpose of this work is both to provide an up-to-date, detailed geological map and to carry out focused geoscientific research in an area where several exploration projects are currently underway. The project is part of an ongoing initiative by MGS to upgrade geological data in areas of Manitoba where the existing maps are outdated.

Mapping by the author is one of four research projects in the BRB. The other projects are as follows: regional mapping and tectonic studies by Duguet et al. (GS-16, this volume), detailed mapping and pegmatite studies by Kremer and Lin (GS-18, this volume) and a study of the Cr and PGE-hosting, mafic-ultramafic Bird River Sill by Mealin (GS-19, this volume). This report presents the results of 1:20 000 scale geological mapping of supracrustal rocks in the BRB, with a focus on stratigraphy and volcanic geochemistry. Uranium-lead radiometric dating is underway to supplement the existing geochronological database in the region; new dates reported here indicate the approximate maximum ages for the deposition of two epiclastic rock formations that postdate the volcanic rocks in the BRB.

Geological mapping in 2006 was conducted by the author in the east and central parts of the BRB throughout June and July. Mapping in the Booster–Bird lakes area extended westward the area investigated in 2005 (Gilbert, 2006). In mid-July, a short mapping program was carried out in a narrow supracrustal belt in the Winnipeg River area that, although separated from the main greenstone belt by a granitoid terrane in the Birse–Shatford lakes area, is considered to be part of the BRB (Figure GS-17-2).

Exploration history, previous work and current exploration

Exploration and geological investigations in the Bird River area span the past century, dating from the pioneering work of Tyrrell (1900). Economic interest in the

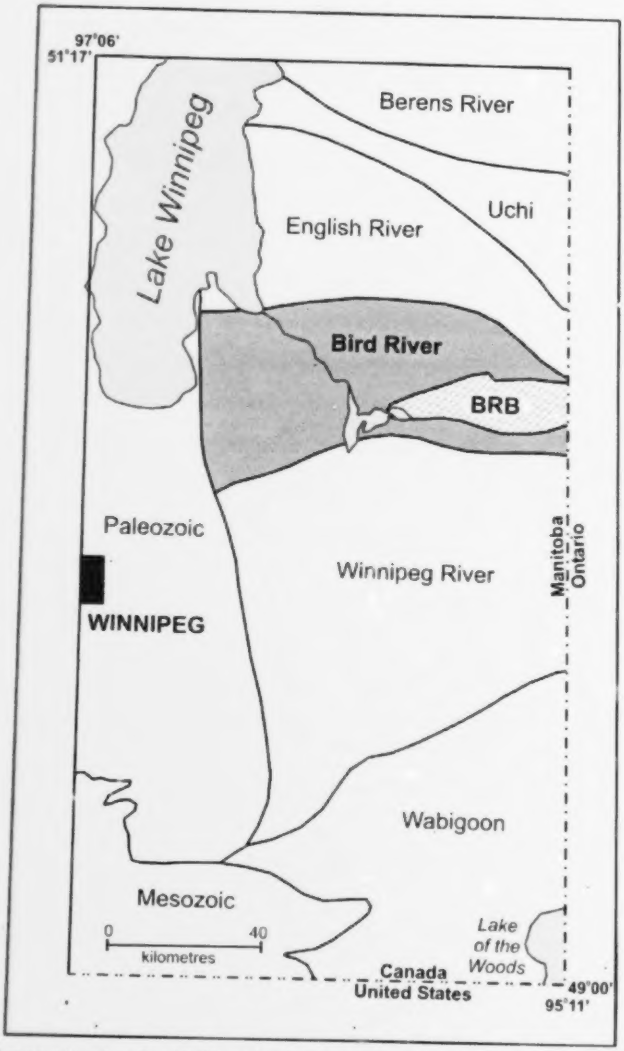
97°06'
51°17'
Lake Winnipeg
Berens River
English River
Uchi
Bird River
BRB
Paleozoic
Winnipeg River
WINNIPEG
Manitoba
Ontario
Wabigoon
Mesozoic
0
40
kilometres
Lake of the Woods
Canada
United States
49°00'
95°11'

Figure GS-17-1: *Regional map showing the BRB and geological domains in southeastern Manitoba.*

region was initially focused on the potential of sporadically occurring, Mo-bearing pegmatites, as well as the discovery of Ni-Cu ore at Cat Lake in the area north of Bird Lake. Subsequent exploration was targeted on rare earth– and Sn-bearing pegmatites at Shatford and Bernic lakes, as well as chromitiferous layers in the mafic-ultramafic Bird River Sill. The Tanco mine at Bernic Lake produced Sn and Ta ore for a brief interval in 1929 and later, in the 1950s, was a source of Li; the mine became fully operational as a Ta producer in 1969. Minor amounts of Cs, Be and Rb were also formerly recovered from the ore at Bernic Lake. The Tanco mine, wholly owned by the Cabot Corporation, is currently an important source of Ta and Cs; the mine is the only Ta producer in North America and contains 60 to 80% of known world reserves of Cs.

In the central part of the BRB, Cu and Ni were produced for a decade until the mid-1970s from the Dumbarton (and subsequently the Maskwa) orebodies, located just a few kilometres north of Bernic Lake. Renewed production of Ni is planned following the delineation of significant reserves in the Maskwa orebody by Mustang Minerals Corp. (Mustang Minerals Corp., 2006). Current exploration in the BRB is focused on PGE, base metals and prospects for new sources of rare earth elements in pegmatites.

The first systematic geological mapping of the BRB was undertaken in the 1950s (Springer, 1948, 1949, 1950; Davies, 1952, 1955a, 1955b, 1956, 1957). Geological investigations were subsequently carried out by Trueman (1971), who produced a study of the Bird River Sill; the sill has also been the subject of geological investigations by Theyer (1981, 1983, 1991, 2002) and Scoates (1983, 1988; Scoates et al., 1987, 1989). The BRB was mapped by Trueman (1980) as a Ph.D. thesis. Cerny at al. (1981)

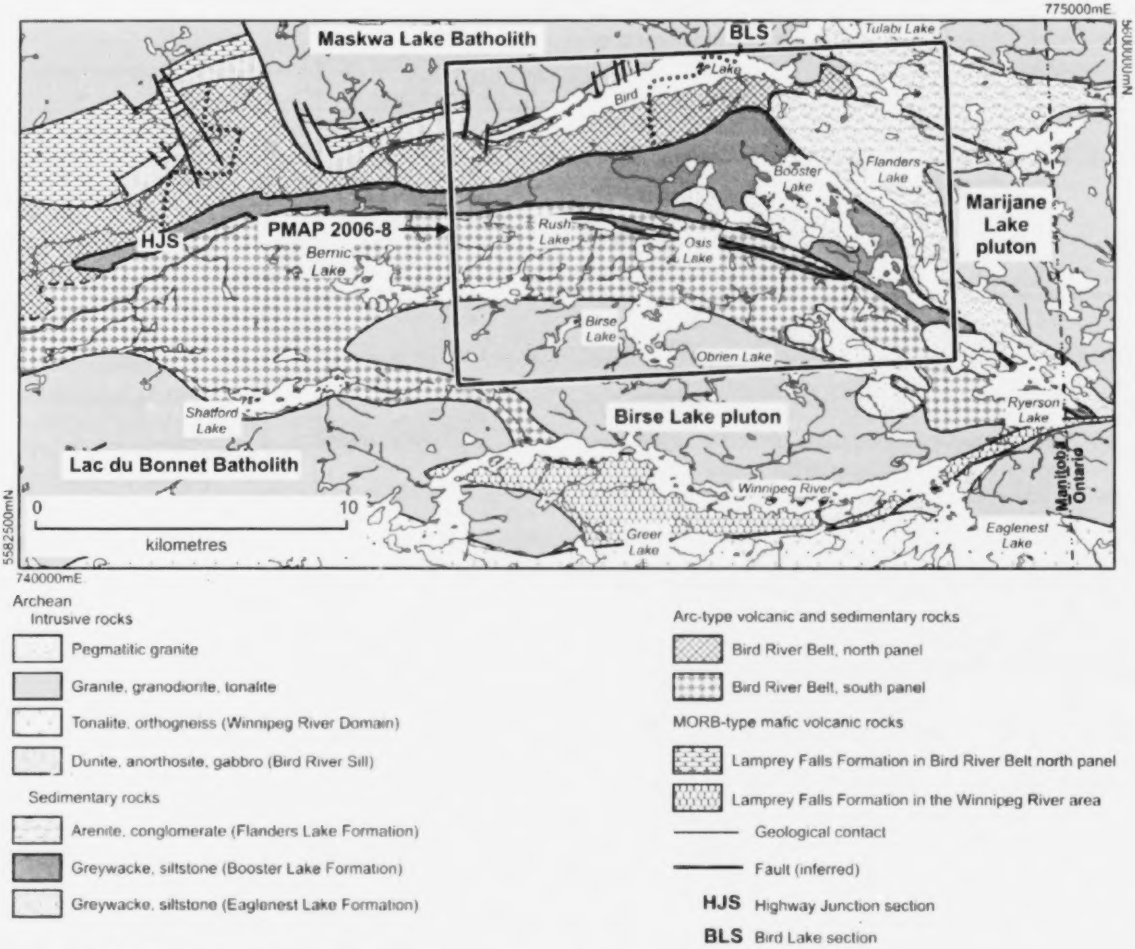
775000mE
5600000mN
Maskwa Lake Batholith
BLS
Tulabi Lake
Bird Lake
Booster Lake
Flanders Lake
Marijane Lake pluton
HJS
PMAP 2006-8
Bernic Lake
Rush Lake
Osis Lake
Birse Lake
Obrien Lake
Shatford Lake
Birse Lake pluton
Ryerson Lake
Lac du Bonnet Batholith
Winnipeg River
Manitoba
Ontario
0
10
kilometres
Greer Lake
Eaglenest Lake
5582500mN
740000mE
Archean
Intrusive rocks
Pegmatitic granite
Granite, granodiorite, tonalite
Tonalite, orthogneiss (Winnipeg River Domain)
Dunite, anorthosite, gabbro (Bird River Sill)
Sedimentary rocks
Arenite, conglomerate (Flanders Lake Formation)
Greywacke, siltstone (Booster Lake Formation)
Greywacke, siltstone (Eaglenest Lake Formation)
Arc-type volcanic and sedimentary rocks
Bird River Belt, north panel
Bird River Belt, south panel
MORB-type mafic volcanic rocks
Lamprey Falls Formation in Bird River Belt north panel
Lamprey Falls Formation in the Winnipeg River area
Geological contact
Fault (inferred)
HJS Highway Junction section
BLS Bird Lake section

Figure GS-17-2: Geological map of the BRB.

provided a comprehensive study of the abundant pegmatite intrusions of the region, as well as a synthesis and interpretation of the regional geology. A 1:250 000 scale geological map (Manitoba Energy and Mines, 1987) represents the most recent compilation of the geology of the area.

Regional setting

The BRB, located between the English River Domain to the north and the Winnipeg River Domain to the south (Figure GS-17-1), has been interpreted as a collage of various tectonostratigraphic components that are deformed in a major synclinorial structure (Cerny et al., 1981). The oldest rocks are MORB-like ocean-floor or BABB-type sequences that constitute both the northernmost structural unit in the BRB and the narrow supracrustal belt approximately 20 km to the southeast, in the Winnipeg River area. Both the northern and southern MORB-like basaltic units were assigned to the 'Lamprey Falls Formation' by Cerny et al. (1981), and that term has been retained in the present mapping. (Figure GS-17-2; Table GS-17-1). The mafic-ultramafic Bird River Sill extends along the south side of the Lamprey Falls Formation in the area west of Bird Lake. In the Winnipeg River area, the south margin of the supracrustal sequence consists of volcanic-derived epiclastic rocks of the Eaglenest Lake Formation (Cerny et al., 1981), assumed to be in fault contact with Lamprey Falls Formation basalt.

The 'northern' Lamprey Falls Formation component at the north margin of the BRB is structurally overlain by an arc-type volcanosedimentary assemblage that constitutes the main part of the greenstone belt. The arc-type sequence was subdivided into the Bernic Lake and Peterson Creek formations by Cerny et al. (1981), but current mapping by the author has indicated a need for a re-evaluation of these stratigraphic subdivisions; hence, the previous terminology has not been adopted in this report. Available U-Pb zircon dates (Wang, 1993) are consistent with a slightly younger age for rhyolitic rocks in the arc-type assemblage (Peterson Creek Formation,

Table GS-17-1: Geological formations in the BRB.

Late intrusive rocks

Granite, pegmatite, granodiorite, tonalite, quartz diorite (Lac du Bonnet Batholith, **2660 ±3 Ma**)

Sedimentary rocks

FLANDERS LAKE FORMATION **(2697 ±18 Ma)**

Lithic arenite, polymictic conglomerate

================== *Fault (inferred)* ==================

BOOSTER LAKE FORMATION **(2712 ±17 Ma)**

Greywacke-siltstone turbidite, conglomerate

~~~~~~~~~~~~~~~~~~ *Unconformity* ~~~~~~~~~~~~~~~~~~

Intrusive rocks

MISCELLANEOUS INTRUSIONS

Gabbro, diorite, quartz-feldspar porphyry; granodiorite (Maskwa Lake Batholith II: **2725 ±6 Ma**) (Pointe du Bois Batholith: **2729 ±9 Ma**)

Metavolcanic and metasedimentary rocks — arc assemblage (2740 ±4 Ma)

Mafic to felsic volcanic and related intrusive rocks; greywacke-siltstone turbidite, chert, oxide-facies iron formation, polymictic conglomerate; derived gneiss and schist

Intrusive rocks

BIRD RIVER SILL **(2745 ±5 Ma)**

Dunite, peridotite, picrite, anorthosite and gabbro

================== *Fault (inferred)* ==================

Metavolcanic and metasedimentary rocks

LAMPREY FALLS FORMATION

Basalt (aphyric to plagioclase-phyric; locally pillowed, amygdaloidal or megacrystic), related volcanic breccia

================== *Fault (inferred)* ==================

EAGLENEST LAKE FORMATION

Greywacke-siltstone turbidite

Older intrusive rocks

Granodiorite (Maskwa Lake Batholith I: **2872 ±11 Ma**, **2844 ±12 Ma**)

2740 ±4 Ma) relative to the Bird River Sill, which is synvolcanic in age (2745 ±5 Ma).

Two sedimentary formations postdate the volcanic rocks by at least 7 m.y.: the greywacke-siltstone turbidite Booster Lake Formation (maximum depositional age 2712 ±17 Ma) and the fluvial-alluvial Flanders Lake Formation (2697 ±18 Ma). These data indicate a probable approximate 30 m.y. age difference between the volcanic and younger epiclastic rocks. Since the contact between these two formations has not been observed, their stratigraphic relationship and relative ages are not known. In the map of Cerny et al. (1981), these formations are in fault
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contact, but new data at Booster Lake indicate a possible conformable relationship. The Booster Lake turbidites extend throughout the length of the BRB, whereas the Flanders Lake sedimentary rocks are confined to the east part of the belt and extend beyond the provincial boundary to the area east of Reynar Lake in Ontario (Gilbert, 2005).

For the purpose of this report, the BRB has been divided into north and south panels, separated by the fault-bounded Booster Lake Formation that extends through the centre of the greenstone belt (Figure GS-17-2). The north panel consists of the 'northern' Lamprey Falls Formation component and the volcanosedimentary sequence immediately to the south that extends to the north margin of the Booster Lake Formation. The south panel consists of the predominantly volcanic sequence that extends southward from the Booster Lake Formation to the granitoid pluton at Birse Lake.

BRB south panel: Booster–Birse lakes section

The south panel of the BRB in the area east of Bernic Lake consists of a diverse assemblage of rhyolitic and basaltic rocks that are assumed to be in intrusive contact with the Birse Lake pluton to the south, and juxtaposed along a faulted contact against south-facing Booster Lake turbidites to the north (Figure GS-17-2). At both the north and south margins of this volcanic sequence, basaltic units up to 0.5 km thick display well-preserved north-facing pillows. The sequence between, and apparently conformable with, the flanking mafic units consists mainly of felsic volcanic rocks, with minor intercalated basalt, that lack stratigraphic facing indicators (Gilbert, 2006).

The felsic and intercalated mafic volcanic rock units in the Booster–Birse lakes section are characterized by a lensoid configuration of units that apparently reflects their original distribution rather than a tectonic interleaving. Contacts between the mafic and felsic volcanic rocks are rarely seen but, where they are exposed, the units appear to be in conformable contact, without conspicuous shearing (Figure GS-17-3). In contrast to the BRB north panel (*see* below), the south panel of the greenstone belt is characterized by tectonic attenuation, locally pervasive metasomatic alteration and abundant pegmatite intrusions that are hindrances to stratigraphic analysis. There is, however, sufficient evidence to show that conglomerate,

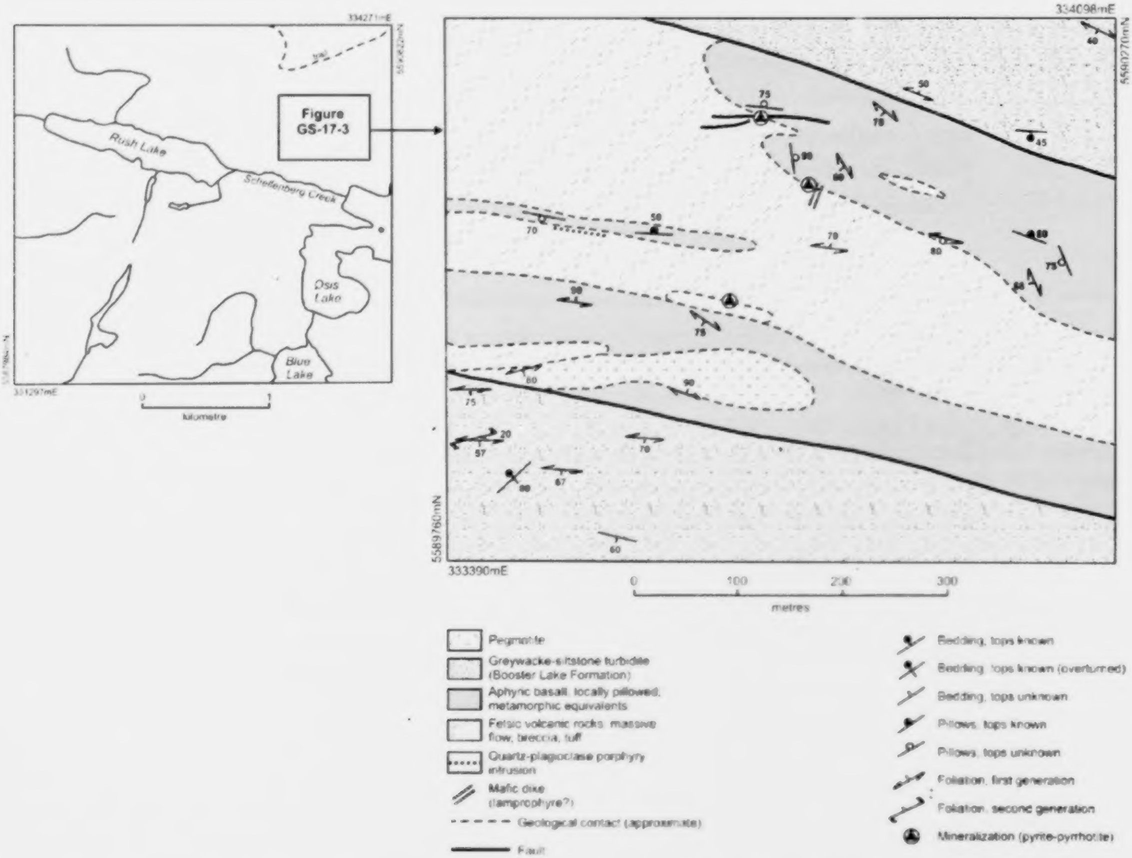
334271mE
Figure GS-17-3
Rush Lake
Schellenberg Creek
Osis Lake
Blue Lake
331297mE
0
1
kilometre
334098mE
5590270mN
5589760mN
333390mE
0
100
200
300
metres
Pegmatite
Greywacke-siltstone turbidite (Booster Lake Formation)
Aphyric basalt, locally pillowed, metamorphic equivalents
Felsic volcanic rocks: massive flow, breccia, tuff
Quartz-plagioclase porphyry intrusion
Mafic dike (lamprophyre?)
Geological contact (approximate)
Fault
Bedding, tops known
Bedding, tops known (overturned)
Bedding, tops unknown
Pillows, tops known
Pillows, tops unknown
Foliation, first generation
Foliation, second generation
Mineralization (pyrite-pyrrhotite)

***Figure GS-17-3:** Simplified geological map of the area east of Rush Lake, south panel of the BRB.*

if present at all, is not a significant part of the sequence, casting doubt on the reliability of previous mapping, which identified conglomerate as the principal component of the section (Cerny et al., 1981).

Felsic fragmental rocks and related massive flows

Felsic volcanic rocks constitute approximately half of the BRB south panel in the area east of Osis Lake and over 80% of the central part of this panel, between the flanking basaltic units at the north and south margins (Figures GS-17-2, -4). The majority of these felsic rocks are fragmental, but massive extrusive and intrusive rhyolitic units occur sporadically within the sequence. Most felsic fragmental rocks in the south part of the sequence are heterolithic and consist of detritus of probable pyroclastic origin that is locally reworked, whereas most felsic breccia units in the north part of the sequence are monolithic, closely associated with extrusive rocks and assumed to be autoclastic in origin. The northernmost 150 m of the felsic volcanic section in the area east of Osis Lake consists of a sequence of massive rhyolite, breccia and felsic tuff that possibly represents an upward-fining sequence to the north.

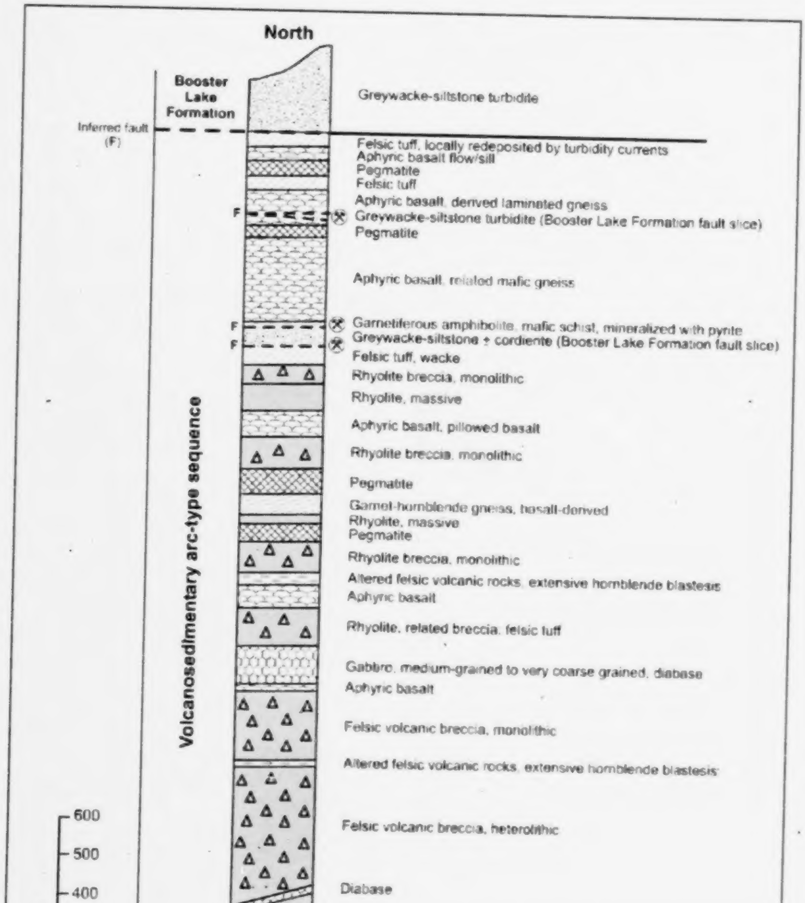
North
Booster Lake Formation
Inferred fault (F)
Greywacke-siltstone turbidite
Felsic tuff, locally redeposited by turbidity currents
Aphyric basalt flow/sill
Pegmatite
Felsic tuff
Aphyric basalt, derived laminated gneiss
F
Greywacke-siltstone turbidite (Booster Lake Formation fault slice)
Pegmatite
Aphyric basalt, related mafic gneiss
F
Garnetiferous amphibolite, mafic schist, mineralized with pyrite
F
Greywacke-siltstone ± cordierite (Booster Lake Formation fault slice)
Felsic tuff, wacke
Rhyolite breccia, monolithic
Rhyolite, massive
Aphyric basalt, pillowed basalt
Rhyolite breccia, monolithic
Pegmatite
Garnet-hornblende gneiss, basalt-derived
Rhyolite, massive
Pegmatite
Rhyolite breccia, monolithic
Altered felsic volcanic rocks, extensive hornblende blastesis
Aphyric basalt
Rhyolite, related breccia, felsic tuff
Gabbro, medium-grained to very coarse grained, diabase
Aphyric basalt
Felsic volcanic breccia, monolithic
Altered felsic volcanic rocks, extensive hornblende blastesis
Felsic volcanic breccia, heterolithic
Diabase
Felsic volcanic breccia, heterolithic; locally reworked by mass flows
F
F
Mafic schist and gneiss, basalt-derived
Felsic volcanic rocks
Aphyric basalt, pillowed basalt (up to 500 m thick)
Volcanosedimentary arc-type sequence
metres
600
500
400
300
200
100
0
Birse Lake pluton
Tonalite, granodiorite, equigranular to porphyritic
South
Base-metal mineralization

Figure GS-17-4: *North-south stratigraphic section of the south panel of the BRB from the Booster Lake Formation to Birse Lake (Booster-Birse lakes section).*

Heterolithic felsic volcanic breccia

Heterolithic felsic volcanic breccia contains angular, plagioclase±quartz-phyric rhyolite fragments, as well as minor intermediate to mafic types. The tuffaceous, felsic to intermediate matrix contains evenly distributed plagioclase grains and is locally characterized by pervasive metasomatism (Figure GS-17-5a). Domains of mafic alteration are locally tectonically disrupted and appear similar to primary fragments. The heterolithic breccia is generally devoid of original layering but, at one locality in the lower part of the section, felsic and sporadic mafic fragments are sorted and graded in 10 to 25 cm thick lensoid units (Figure GS-17-5b). The clasts are angular to subangular and the unit is interpreted as a reworked pyroclastic deposit, possibly emplaced by mass flow.

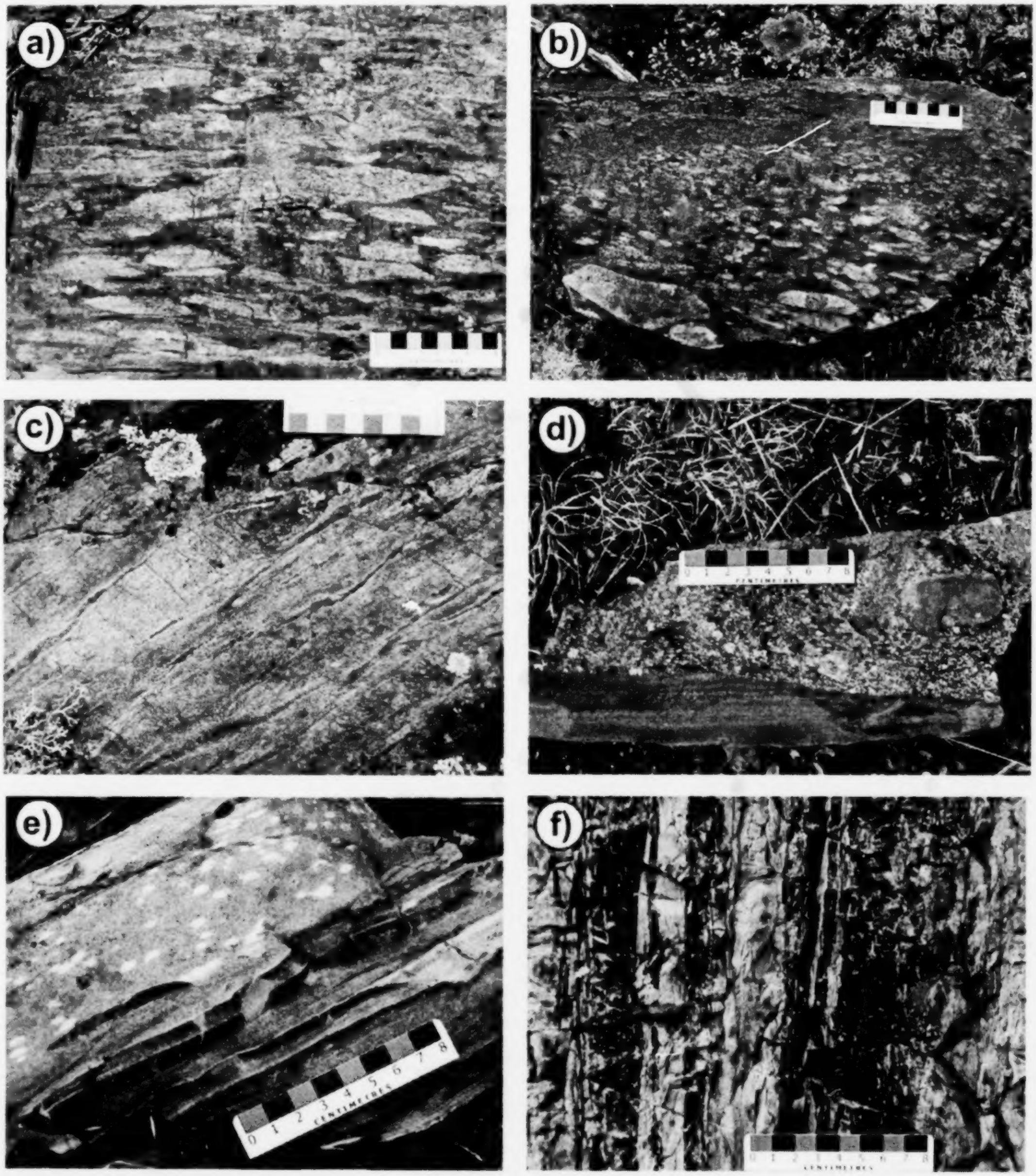

*Figure GS-17-5: **a)** Heterolithic felsic breccia with altered mafic matrix (BRB south panel); **b)** reworked felsic volcanic breccia displaying normal size-grading (BRB south panel); **c)** thermal contraction fractures in massive rhyolite flow (BRB south panel); **d)** laminated tuff scoured by sediment gravity flow that deposited the overlying lapilli tuff bed (Highway Junction section, unit 1W); **e)** scoured chert laminae with rip-ups in greywacke turbidite (Highway Junction section, unit 3W); **f)** bedded chert within 23 m thick member (Highway Junction section, unit 5W).*

Monolithic felsic volcanic breccia

Monolithic felsic volcanic breccia occurs both as minor fragmental zones within massive rhyolite flows and as more conspicuous breccia deposits that contain subordinate massive components. One breccia unit, located close to the southeast corner of the map area (Gilbert, 2006), is up to 200 m thick and consists of a monolithic assemblage of pebble- to cobble-sized, angular rhyolitic fragments in a felsic matrix. Spherulitic texture is locally characteristic of both the fragments and matrix, which is thus assumed to have been originally magmatic (as opposed to tuffaceous) in origin.

Felsic tuff

Felsic tuff is common in the upper part of the Booster–Birse lakes section. One 65 m thick tuff unit at the top (north margin) of the sequence extends laterally for over 4 km in the area between Osis Lake and the south part of Booster Lake (Gilbert, 2006). The rock contains detrital felsic grains and localized, fine diffuse laminae but is otherwise devoid of bedding. Farther east, the same unit is characterized by more conspicuous bedding (at a scale of 0.5–4 cm), minor siltstone laminae and detrital grains of quartz and plagioclase up to 5 mm, suggesting the tuffaceous rocks were locally redeposited by turbidity currents, together with finer grained detritus.

Massive rhyolite

Massive rhyolite flows constitute a minor part of the Booster–Birse lakes section. The flows are typically 10 to 20 m wide and locally characterized by a plagioclase-(quartz)-phyric texture that confirms their magmatic origin; in some units, thin anastomosing micaceous stringers are interpreted as derived from thermal contraction fractures, subparallel to the surface of the volcanic flow (Figure GS-17-5c). Some flows contain zones of in situ brecciation that are gradational with autoclastic breccia domains.

Alteration in felsic volcanic rocks

Primary features in felsic volcanic rocks within the BRB south panel are locally obscured by metasomatic alteration and subsequent metamorphic recrystallization. Such alteration occurs both as sporadic minor domains and in a conformable metasomatic zone in the central part of the felsic fragmental sequence that is characterized by pervasive hornblende blastesis (Figure GS-17-4). Immediately east of Osis Lake, this metasomatic zone is associated with a ground magnetic anomaly and contains several mineralized pyritic units over a 10 m wide interval. The mineralization occurs north of a coarsely porphyroblastic, 18 m thick unit of chlorite-sericite-cordierite(?)-bearing gneiss. A conspicuous aeromagnetic anomaly that coincides with the mineralized zone extends along strike for more than 10 km from Osis Lake to the area south of Summerhill Lake (Gilbert, 2006; Geological Survey of Canada, 1966).

Basalt, aphyric, mostly pillowed; related amphibolite and mafic gneiss

Basaltic units, ranging from 10 to 500 m in thickness, are intercalated with felsic volcanic units in the BRB south panel. The thickest and best preserved of these mafic units occur at or close to both the north and south margins of the Booster–Birse lakes section. Basaltic rock units in the stratigraphic interval between the northern and southern units are compositionally similar to, but typically more altered and deformed than, the flanking mafic volcanic units. Reliable pillow-top indicators are largely confined to the latter units, which are north facing in both cases.

The basalt is aphyric with moderate-sized pillows, typically 0.5 to 1 m long, and sporadic larger pillows up to 2.5 m by 0.7 m. Dark grey or yellow-grey weathering selvages reflect secondary chloritic and epidotic minerals, respectively. Tectonic attenuation varies from moderate to severe, but locally the mafic flows are almost undeformed, due to the fact that tectonic strain was confined to narrow (0.5–1 m) incompetent zones in which the basalt was altered to mafic schist and gneiss. Polygonal cooling fractures occur in one flow in the south part of the Booster–Birse lakes section. The pillowed basalt flows are assumed to be compositionally akin to juvenile-arc-type basalt. Alteration of the basalt to more siliceous and/or feldspathic compositions, which is interpreted to be due to synvolcanic hydrothermal fluids, occurs both at a small, within-pillow scale and also in larger, conformable zones that are locally associated with pyritic mineralization.

A conspicuous alteration zone occurs at the south margin of the thick (450 m) pillowed basalt unit that extends along the north flank of the BRB south panel Gilbert, 2006). This zone was examined at three localities over a strike length of 8 km. At the easternmost locality, intense silicification occurs over a 3 m wide zone that is part of a wider (~30 m) section where the basalt is highly attenuated and variously altered to quartz-plagioclase-hornblende-garnet gneiss, characterized by localized pervasive quartz veins and patchy gossan staining. Approximately 5 km west-northwest, stratigraphically equivalent basalt at the margin of the same volcanic unit is pervasively altered and characterized by chloritic schist, garnet-bearing gneiss and massive, very coarse grained garnetite over a 20 m wide zone. These garnetiferous gneisses locally contain pyrite-pyrrhotite mineralization, extensive gossan staining and a spatially associated magnetic anomaly. Similar pyrite-pyrrhotite mineralization is present at the same stratigraphic horizon near the east end of Rush Lake, approximately 8 km west-northwest of the first-described occurrence. At the

Rush Lake locality, the mineralization occurs at the contact between basalt and rhyolite, and is associated variously with a) a shear zone oblique to the volcanic rock contact, and b) a mafic (lamprophyre?) dike that intersects the contact.

BRB north panel

The BRB north panel is that part of the greenstone belt between the Maskwa Lake Batholith to the north and the Booster Lake Formation to the south (Figure GS-17-2). Compared to the BRB south panel, the north panel is both lithologically more diverse and, in general, better preserved, thus facilitating detailed stratigraphic analysis. Reconnaissance mapping and detailed north-south transects through the BRB north panel have led to a provisional interpretation that the section is a south-facing monocline.

The MORB-like Lamprey Falls Formation is the northernmost component of the BRB and is structurally overlain by volcanic and sedimentary rocks to the south that are geochemically akin to modern arc-type volcanic rocks (Gilbert, 2005). A major structural break is inferred between these two components on the basis of their contrasting geochemical affinity and, locally, a conspicuous topographic lineament at the contact that may correspond to a major fault or shear zone. The mafic to ultramafic Bird River Sill is coincident with a part of this structural discontinuity and is locally seen to intrude the Lamprey Falls Formation (Mealin, GS-19, this volume). South of the Bird River Sill, a stratigraphic disconformity within the arc-type sequence is indicated by a 75 m wide, polymictic conglomerate unit.

Lamprey Falls Formation

The Lamprey Falls Formation at the north margin of the BRB, which is geochemically akin to modern BABB (Gilbert, 2005), consists mainly of massive to pillowed, aphyric flows that are invariably south facing. Basaltic flow-breccia, mafic tuff and synvolcanic gabbro are subordinate components, and a unit of plagioclase-megacrystic basalt occurs close to the top of the formation (Trueman, 1980). South of the Lamprey Falls basalt, structurally overlying arc-type rocks have been interpreted as relatively younger (Cerny at al., 1981; Gilbert, 2005; Duguet et al., 2005). This interpretation is supported by the occurrence, within the Lamprey Falls Formation, of a younger porphyritic andesite dike with an arc-type rare earth element (REE) profile that is virtually identical to that of a porphyritic basalt flow within the arc-type sequence (Figure GS-17-6a). Mid-ocean-ridge basalt (MORB)–like

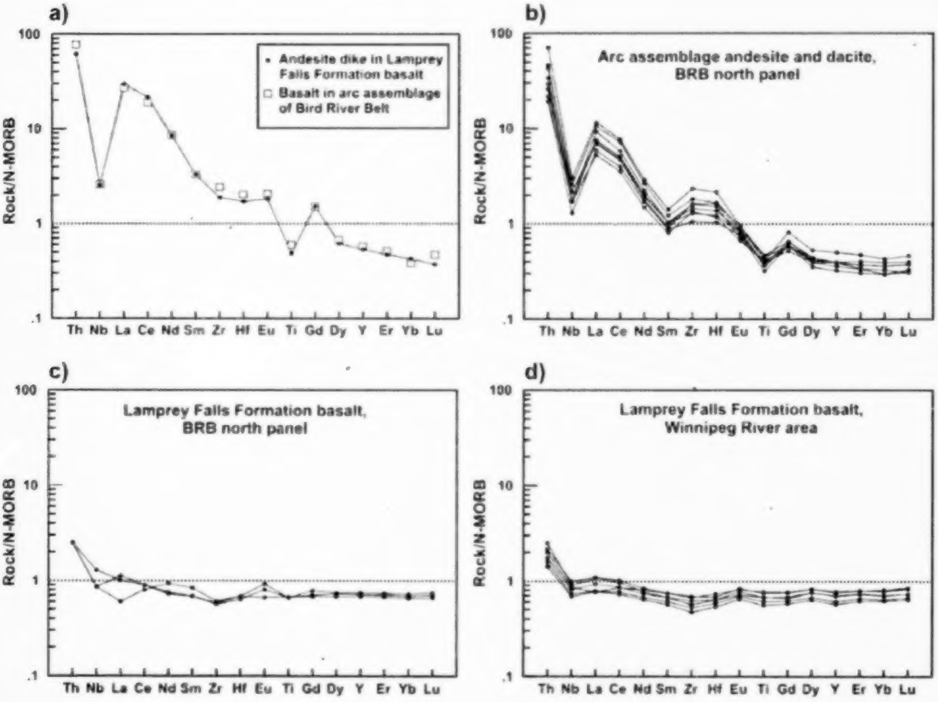

Figure GS-17-6: *Extended element plots of **a)** plagioclase-phyric basalt flow of juvenile-arc affinity within the volcanosedimentary section, north panel of the BRB and a porphyritic andesite dike of juvenile-arc affinity, emplaced within Lamprey Falls Formation basalt, 20 km west of the flow; **b)** arc assemblage basalt in the BRB north panel; **c)** mid-ocean-ridge basalt (MORB)–like Lamprey Falls Formation basalt in the BRB north panel; **d)** MORB-like Lamprey Falls Formation basalt at the Winnipeg River. Normalizing values are after Sun and McDonough (1989).*

Lamprey Falls Formation basalt in the BRB north panel and geochemically analogous Lamprey Falls basalt at the Winnipeg River exhibit flat, slightly depleted REE patterns (relative to N-MORB) with moderately elevated Th content, in contrast to the profiles of BRB arc assemblage volcanic rocks (Figure GS-17-6b, -6c, -6d).

Arc-type volcanosedimentary sequence

Two transects were made through the volcanosedimentary sequence in the BRB north panel (Figure GS-17-2): a western transect ('Highway Junction section') in the vicinity of the junction between Provincial Roads 314 and 315, and an eastern transect in the Bird Lake area. Stratigraphic units in the western transect (Figure GS-17-7) are numbered 1W to 15W, to distinguish them from units 1E to 8E in the eastern transect (*see* 'Bird Lake section' below). No correlation is implied between units with the same number in these two stratigraphic sections. Brief summaries of the two stratigraphic sections are provided in this report; more detailed lithological descriptions of individual rock units are provided in Data Repository Item DRI2006002[1].

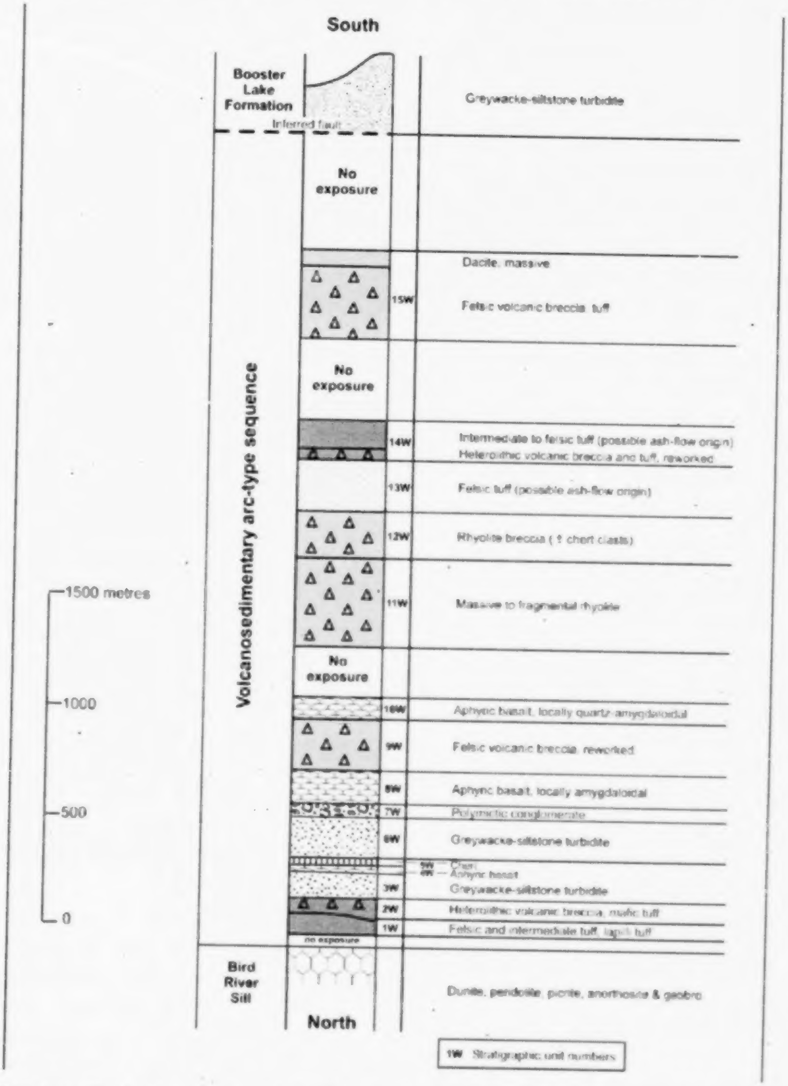
South
Booster Lake Formation
Inferred fault
Greywacke-siltstone turbidite
No exposure
Dacite, massive
15W
Felsic volcanic breccia, tuff
No exposure
Volcanosedimentary arc-type sequence
14W
Intermediate to felsic tuff (possible ash-flow origin)
Heterolithic volcanic breccia and tuff, reworked
13W
Felsic tuff (possible ash-flow origin)
12W
Rhyolite breccia (? chert clasts)
11W
Massive to fragmental rhyolite
No exposure
10W
Aphyric basalt, locally quartz-amygdaloidal
9W
Felsic volcanic breccia, reworked
8W
Aphyric basalt, locally amygdaloidal
7W
Polymictic conglomerate
6W
Greywacke-siltstone turbidite
5W — Chert
4W — Aphyric basalt
3W
Greywacke-siltstone turbidite
2W
Heterolithic volcanic breccia, mafic tuff
1W
Felsic and intermediate tuff, lapilli tuff
no exposure
Bird River Sill
Dunite, peridotite, picrite, anorthosite & gabbro
North
1500 metres
1000
500
0
1W Stratigraphic unit numbers

Figure GS-17-7: *South-north stratigraphic section of the north panel of the BRB, in the vicinity of the junction between Provincial Roads 314 and 315 ('Highway Junction section').*

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[1] MGS Data Repository Item DRI2006002, containing the data or other information sources used to compile this report is available online to download free of charge at www2.gov.mb.ca/itm-cat/freedownloads.htm or on request from minesinfo@gov.mb.ca, or Mineral Resources Library, Manitoba Science, Technology, Energy and Mines, 360–1395 Ellice Avenue, Winnipeg, MB R3G 3P2, Canada.

Highway Junction section

The 3.75 km Highway Junction section contains fifteen separate map units in a predominantly south-facing sequence. The northernmost 0.65 km part of this section comprises seven units that consist exclusively of sedimentary and reworked volcaniclastic rocks, except for a minor unit of aphyric pillowed basalt. Southward stratigraphic facing in this northern part of the section is indicated by exceptionally well preserved turbidite features within the epiclastic rock units, as well as by scouring in reworked volcaniclastic rocks at the base of the sequence (Figure GS-17-5d). Localized folding, however, is indicated approximately 0.5 km above the base by a north-facing scoured contact within south-facing turbidite beds. Duguet et al. (GS-16, this volume) also reported top reversals in this part of the sequence. The remaining part of the Highway Junction section consists of felsic and subordinate mafic flows and volcanic fragmental rocks that were locally redeposited by subaqueous mass flows.

Stratigraphic transect

The northernmost seven units (1W to 7W) of the Highway Junction section (Figure GS-17-7) consist of a diverse assemblage of felsic to mafic tuff, related epiclastic deposits and minor basalt. Rip-ups, load structures, scour and disrupted bedding in the clastic rocks suggest a high-energy depositional environment characterized by turbidity currents and possible gravity-induced mass flows (Figure GS-17-5e). A 15 to 30 m thick, aphyric basalt unit (4W) is an apparently conformable member within this volcaniclastic-epiclastic sequence. A conspicuous, 23 m thick chert member (unit 5W; Figure GS-17-5f) overlying the basalt is locally disrupted and folded due to soft-sediment deformation.

Polymictic conglomerate (unit 7W) derived mainly from basalt (Figure GS-17-8a) constitutes the uppermost sedimentary unit within the northern, epiclastic-volcaniclastic part of the Highway Junction section. The unsorted conglomerate is approximately 75 m thick and contains cobbles and sporadic boulders up to 65 cm by 12 cm, including clasts of banded chert (Figure GS-17-8b) that match closely the well-bedded chert of unit 5W, approximately 175 m stratigraphically below the conglomerate deposit (Figure GS-17-5f).

The central part of the Highway Junction section consists of aphyric basalt and massive to fragmental rhyolite (units 8W to 12W; Figure GS-17-8c), as well as felsic lithic-crystal tuff of possible ash-flow origin (unit 13W). No stratigraphic facing indicators were observed in the sequence from unit 8W to 13W, but a reworked volcaniclastic deposit to the south (unit 14W) displays scour, rip-ups (Figure GS-17-8d), graded bedding and flame structures that indicate the unit is south facing. The uppermost unit in the sequence (15W) consists of felsic volcanic fragmental rocks, related dacite and intrusive porphyry.

Bird Lake section

Stratigraphic details of the northern, 0.5 km to 1 km wide part of the Bird Lake section (Figure GS-17-9) are incomplete because much of the section there is covered by the lake, but some comparisons can be made between this part of the Bird Lake section and the Highway Junction section (Figure GS-17-7) on the basis of facies types. Higher metamorphic grade and stronger deformation in the Bird Lake section have apparently resulted in the loss of some primary features, thus hindering direct comparison between individual, lithologically defined units within the two sections.

The north part of the Bird Lake section is a predominantly epiclastic sequence that is assumed to correspond to the lower (northern) part of the Highway Junction section (Figure GS-17-7, units 1W–7W). Stratigraphic-top indicators are virtually absent in the Bird Lake area, but the section is assumed to face south on the basis of its similarity with the sequence in the south-facing Highway Junction section to the west. A single case of south-facing crossbeds in the west part of Bird Lake is consistent with this interpretation. The south parts of both sections consist largely of massive to fragmental felsic volcanic rocks and related intrusive units. The Bird Lake sequence appears to be relatively less diverse overall; for example, there are no counterparts of several units that were documented in the Highway Junction section (e.g., 1W, 2W, 5W, 7W and 14W). On the other hand, in the latter section, there are no analogues to the oxide-facies iron formation and remarkable porphyroblastic metasedimentary rocks that occur in the central and west parts of Bird Lake.

Stratigraphic transect

Fine-grained metasedimentary rocks interpreted as turbidite deposits (Figure GS-17-9, unit 1E) extend for over 3.5 km along the south shore of eastern Bird Lake; the estimated maximum width of the unit is 0.65 km. A massive to fragmental, felsic volcanic unit over 200 m thick (unit 2E) occurs within the north (inferred lower) part of unit 1E. The felsic rocks underlie islands in the east-central part of Bird Lake (Dean Islands; Gilbert, 2006), so contact relationships between units 1E and 2E are not seen.

Aphyric, pillowed basalt (unit 3E), assumed to overlie the thick turbidite sequence (unit 1E), has been mapped at two localities in the eastern Bird Lake area. The mafic flow unit is at least 110 m thick where it intersects Booster Creek, immediately north of Provincial Road 315; a pillowed basalt flow interpreted as stratigraphically equivalent occurs 3 km farther west, on a small island close to the south shore of Bird Lake. This flow is

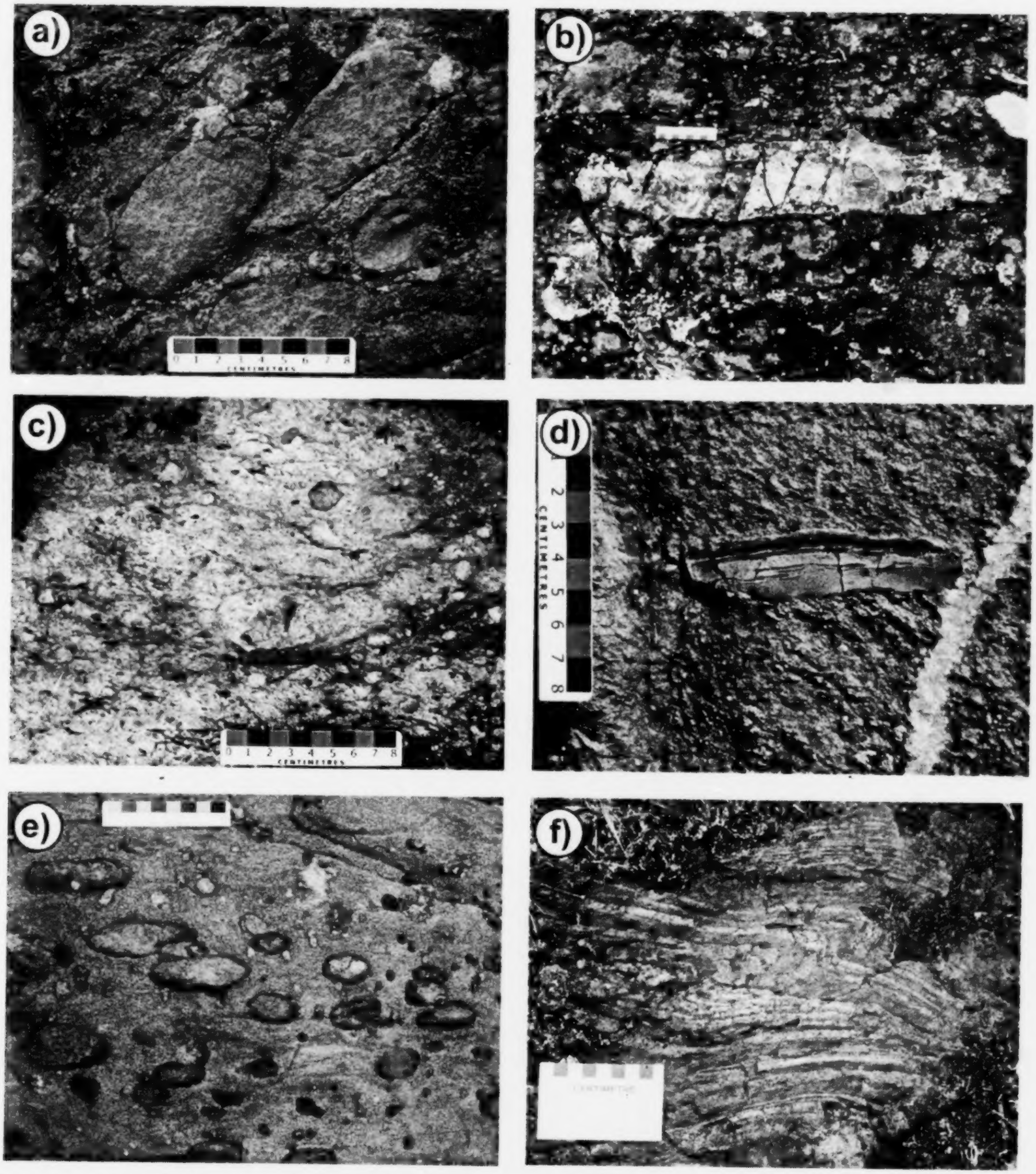


Figure GS-17-8: a) *Polymictic conglomerate (Highway Junction section, unit 7W);* ***b)*** *Layered chert boulder in polymictic conglomerate (Highway Junction section, unit 7W);* ***c)*** *Massive rhyolite with breccia domains (Highway Junction section, unit 11W);* ***d)*** *Chert rip-up in lapilli tuff, interpreted as a reworked volcaniclastic deposit (Highway Junction section, unit 14W);* ***e)*** *Garnet and oval cordierite porphyroblasts in metasiltstone (Bird Lake section, unit 4E);* ***f)*** *Bedded chert and magnetiferous siltstone (Bird Lake section, unit 6E).*

apparently conformable with a 6 m thick mineralized oxide-facies iron formation to the south, which is associated with porphyroblastic metasiltstone (Figure GS-17-8e), gneiss and amphibolite (unit 4E).

South of the iron formation (unit 4E), a 1.25 km thick sequence of massive and related fragmental rhyolite (unit 5E) extends throughout the area south of Bird Lake between Provincial Road 315 and the Booster Lake Formation (Gilbert, 2006). At least two massive rhyolite phases can be distinguished: sparsely plagioclase phyric and coarsely quartz-plagioclase phyric. Garnetiferous gneiss derived from altered felsic volcanic rock occurs sporadically within unit 5E. The south margin of the unit is strongly mylonitized close to the contact with the Booster Lake Formation.

Oxide-facies iron formation (unit 6E) occurs within

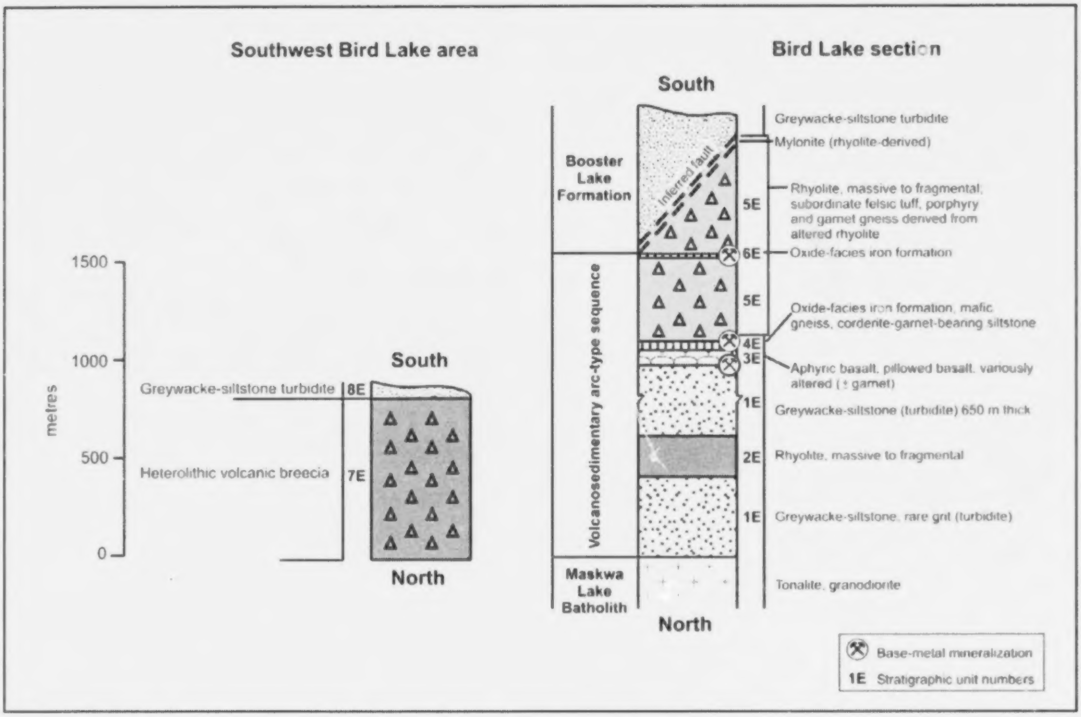

Southwest Bird Lake area
1500
1000
500
0
metres
South
Greywacke-siltstone turbidite
8E
Heterolithic volcanic breccia
7E
North
Bird Lake section
South
Booster Lake Formation
Volcanosedimentary arc-type sequence
Maskwa Lake Batholith
Inferred fault
5E
6E
5E
4E
3E
1E
2E
1E
North
Greywacke-siltstone turbidite
Mylonite (rhyolite-derived)
Rhyolite, massive to fragmental, subordinate felsic tuff, porphyry and garnet gneiss derived from altered rhyolite
Oxide-facies iron formation
Oxide-facies iron formation, mafic gneiss, cordierite-garnet-bearing siltstone
Aphyric basalt, pillowed basalt, variously altered (± garnet)
Greywacke-siltstone (turbidite) 650 m thick
Rhyolite, massive to fragmental
Greywacke-siltstone, rare grit (turbidite)
Tonalite, granodiorite
Base-metal mineralization
1E Stratigraphic unit numbers

***Figure GS-17-9:** South-north stratigraphic section of the north panel of the BRB, from the Booster Lake Formation to Bird Lake ('Bird Lake section').*

the felsic volcanic sequence (unit 5E) at a locality east of Booster Creek (Gilbert, 2006). Unit 6E consists of thinly interlayered magnetiferous siltstone and chert in units up to 8 m thick (Figure GS-17-8f). Patchy pyrite mineralization is characteristic of these strata, which are associated with a prominent positive aeromagnetic anomaly (Geological Survey of Canada, 1966).

Southwest Bird Lake area

Heterolithic breccia (unit 7E) and turbidite deposits (unit 8E) in the southwest part of Bird Lake are of uncertain age and stratigraphic position relative to units 1E to 6E in the Bird Lake section (Figure GS-17-9). Heterolithic volcanic breccia at least 850 m thick (unit 7E) extends for 2.8 km along the south shore of western Bird Lake. The breccia contains a variety of fragment types assumed to be derived from the arc-type volcanic sequence, including mafic to felsic volcanic clasts, subordinate fine-grained tonalite and possible sedimentary detritus. The deposit is unsorted, with angular to subrounded fragments ranging up to boulder size (e.g., 1 m by 2 m; Figure GS-17-10a). Elsewhere, the breccia contains rows of small blocks, possibly aligned during mobilization and emplacement of the unit by subaqueous mass flow (Figure GS-17-10b). At several localities, the fragmental deposit contains sporadic clasts with a penetrative foliation that appears to predate emplacement of the mass flow (Figure GS-17-10c). In the southwest part of Bird Lake, the volcanic breccia (unit 7E) is porphyroblastic with small micaceous aggregates (2–4 mm), as well as larger cordierite porphyroblasts. The cordierite occurs both as rare dark blue, pseudohexagonal crystals (Figure GS-17-10d) and as elongate anhedral porphyroblasts up to 25 cm by 4 cm in size.

A well-layered turbidite deposit (unit 8E), >20 m thick, is assumed to overlie the heterolithic breccia (unit 7E) at the west end of Bird Lake. Unit 8E consists of partly carbonatized, intermediate to felsic wacke and siltstone, interlayered at a scale of 3 to 35 cm and characterized by abundant, stratabound ovoid cordierite porphyroblasts up to 1 cm long.

Both the structural setting and the age of units 7E and 8E are unknown because their contacts are not exposed. Unit 7E appears to occupy an equivalent stratigraphic position to that of the fine-grained sedimentary rocks of unit 1E in the east part of Bird Lake: both units occupy the northernmost part of the supracrustal sequence in the Bird Lake area (Gilbert, 2006). Heterolithic breccia of unit 7E locally contains foliated fragments that appear to have been metamorphosed prior to their incorporation in the mass flow deposit. If this deposit does contain previously metamorphosed detritus derived from the arc-type volcanosedimentary assemblage (units 1E to 6E), a significant difference in age is indicated between the two rock sequences. Similarly, the cordierite-bearing,

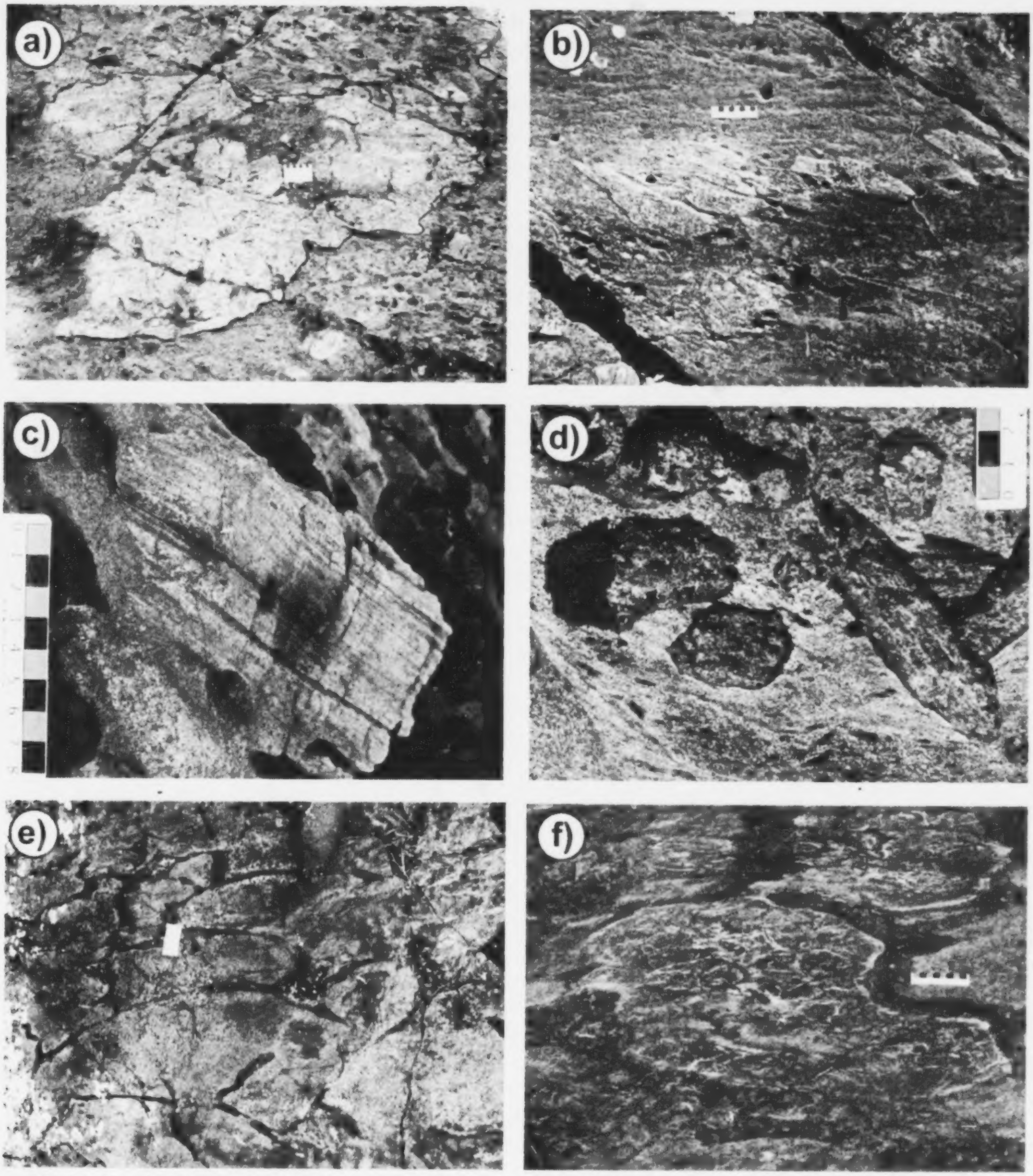


Figure GS-17-10: ***a)*** *Rhyolite boulder in heterolithic breccia interpreted as a mass flow deposit (southwest Bird Lake area, unit 7E);* ***b)*** *Aligned clasts in heterolithic breccia (southwest Bird Lake area, unit 7E);* ***c)*** *Epiclastic fragment with foliation predating incorporation in mass flow deposit (southwest Bird Lake area, unit 7E);* ***d)*** *Cordierite porphyroblasts in matrix of mass flow deposit (southwest Bird Lake area, unit 7E);* ***e)*** *Aphyric pillowed basalt (Lamprey Falls Formation, south shore of the Winnipeg River);* ***f)*** *Polygonal, metasomatic alteration pattern within pillowed basalt (Lamprey Falls Formation, south shore of the Winnipeg River).*

turbiditic sedimentary rocks of unit 8E may also postdate the arc volcanic rocks; the porphyroblastic unit is more comparable to rocks in the relatively younger Booster Lake Formation than the turbidites (unit 1E) in the east part of Bird Lake that are assumed to be part of the arc assemblage and represent an alternative analogous unit. On the other hand, there are no lithologically similar counterparts of the volcanic fragmental unit (unit 7E) in either of the two 'younger' BRB formations (Booster Lake and Flanders Lake formations), which are known to postdate the volcanic rocks (*see* discussion in 'Booster Lake Formation' below). In conclusion, units 7E and 8E are provisionally assigned to the arc-type volcanosedimentary sequence, pending further investigations of the local and regional stratigraphy.

Booster Lake Formation

New data on the turbidite sequence at Booster Lake were added this year to the mapping in 2005, which documented a series of northwest- to west-trending D_1 folds in the fine-grained epiclastic sequence (Gilbert, 2005). An additional northwest-trending, synclinal fold axis was delineated along the northeast margin of the formation, which thus has a 'back-to-back' contact relationship with northeast-facing conglomerate of the Flanders Lake Formation immediately to the northeast (Gilbert, 2006). This relationship suggests that the formational contact is unconformable and/or faulted. The turbidites are mainly intermediate in composition, but felsic wacke interbeds occur locally, especially toward the east margins of the formation at Booster and Summerhill lakes. The metamorphic grade appears to increase slightly in the southeast part of the turbidite basin.

Volcanic-derived conglomerate is interlayered with fine-grained turbidite beds along the northeast shore of the island immediately southeast of Penzick Island, in the northeast part of Booster Lake (Gilbert, 2006). The conglomerate interbeds contain fragments of aphyric basalt, rhyolite, felsic porphyry and possible quartz, which together constitute up to 60% of the rock. The clasts (pebbles, cobbles and sporadic boulders) are strongly attenuated, with elongation ratios of approximately 1:7. Conglomerate units are up to 2 m thick and intimately intercalated with greywacke, pebbly wacke and cordierite-bearing siltstone units. These strata, which are close to the hinge zone of a major synclinal fold at the northeast margin of the Booster Lake Formation, may represent the youngest rocks in the turbidite sequence. The closest rock outcrop in the stratigraphic sequence to the northeast is polymictic conglomerate of the Flanders Lake Formation. Conglomerate interbeds are found nowhere else within the turbidite section at Booster Lake, although conglomerate has been reported elsewhere in the formation, possibly confined to the west part of the turbidite basin, where it is locally associated with sulphide-facies iron formation (Cerny et al., 1981).

The stratigraphic significance of the conglomerate interbeds is uncertain. They are provisionally interpreted as part of a transitional facies between the turbidite sediments (Booster Lake Formation) and fluvial-alluvial sequence to the northeast (Flanders Lake Formation), because they appear to be unique in the east part of the turbidite basin and occur at a stratigraphic interval where relatively finer grained sediments (rather than conglomerate) might be anticipated in a waning turbidite sequence. Nevertheless, both the structural data (indicating a back-to-back relationship) and new geochronological data (*see* below) are more consistent with an unconformity between these two sedimentary formations. Further work is required to determine the significance of the interlayered greywacke-conglomerate section at this locality.

Geochronology

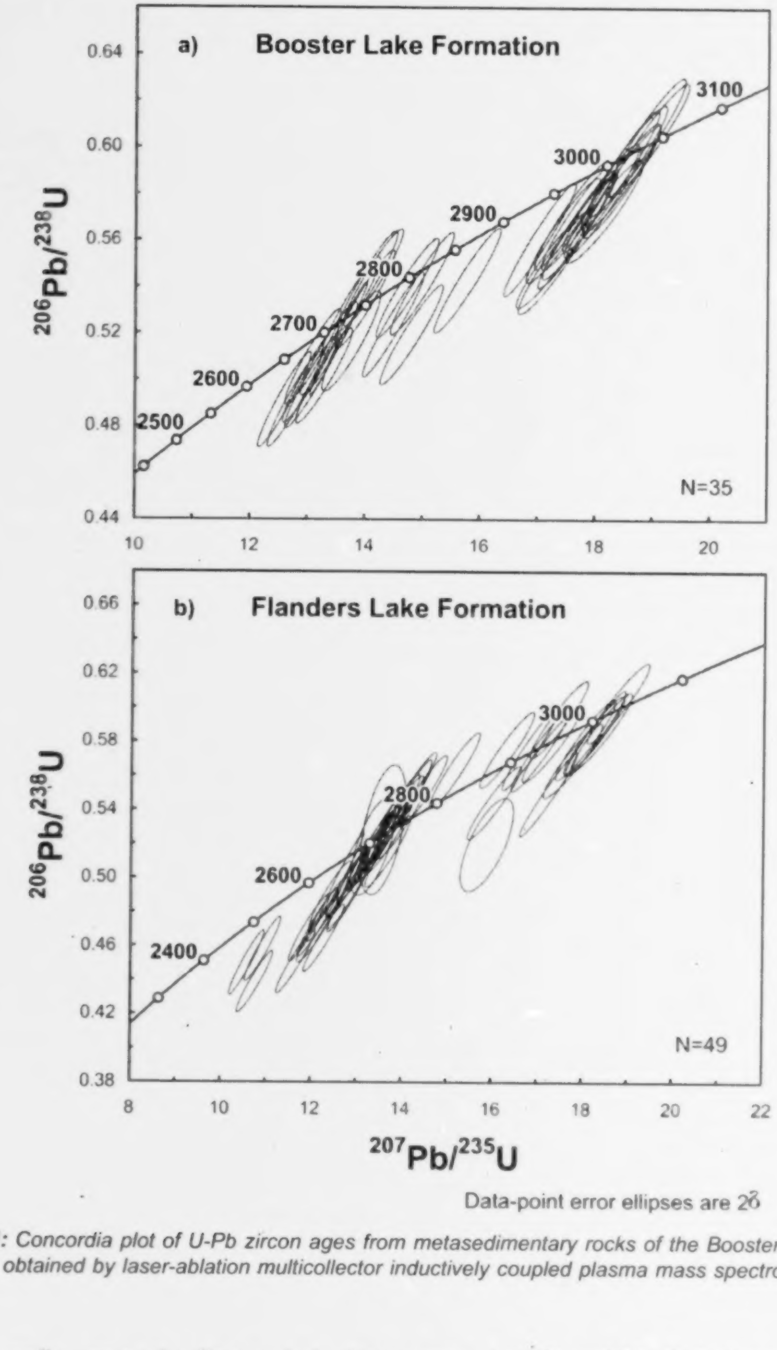
New U-Pb isotope data on zircons from metasedimentary rocks in the eastern BRB confirm previous interpretations that a significant age difference exists between the arc-type assemblage in the Bird Lake area (previously described as the Peterson Creek and Bernic Lake formations; Cerny et al., 1981) and younger sedimentary rocks of the Booster Lake and Flanders Lake formations (Gilbert, 2005; Duguet et al., 2005). The youngest analyzed detrital zircon in a sample of Booster Lake Formation turbidite yielded a subconcordant age of 2712 ±17 Ma, which currently serves as the best estimate for the maximum age of deposition (Figure GS-17-11). Comparing this with the 2740 ±4 Ma age for a felsic volcanic unit in the arc-type assemblage (Peterson Creek Formation; Wang, 1993) suggests an approximate 30 m.y. age difference between the Booster Lake Formation and older arc-type rocks in the BRB.

Uranium-lead isotope analysis of zircons from the Flanders Lake Formation supports this observation, but the data do not establish the relative ages of the Booster Lake and Flanders Lake formations. The U-Pb concordia plot of Flanders Lake Formation zircon data includes several relatively young but discordant zircons (Figure GS-17-11b); the youngest concordant zircon age obtained for the Flanders Lake Formation is 2697 ±18 Ma, tentatively suggesting a slightly younger maximum age for deposition of the Flanders Lake Formation relative to the age of Booster Lake turbidite sedimentation.

Two principal sources of detrital zircons are indicated by the data for both Booster Lake and Flanders Lake epiclastic rocks (Figure GS-17-12). Spikes at ca. 2710 to 2730 Ma are assumed to represent a volcanosedimentary source corresponding to arc volcanism in the BRB, whereas ca. 3025 Ma spikes are attributed to older granitoid plutonism. The relative importance of these two sources is different for the two sedimentary formations: that is, the Booster Lake Formation contains relatively more detritus from the 'older' granitoid terrane, whereas, in the Flanders Lake Formation, detritus derived from ca. 2740 Ma volcanism is predominant. The ancient (ca. 3430 Ma) zircon shown in the Booster Lake Formation (Figure GS-17-12a) is noteworthy, and may be interpreted as evidence for a detrital source component in the Winnipeg River Domain (M.T. Corkery, pers. comm. 2006).

Structural inliers in the BRB south panel

At least two fault slices of the Booster Lake Formation occur within the volcanic sequence that forms the south panel of the BRB (Gilbert, 2006). The more conspicuous of these units extends laterally for over 8 km from the area north of O'Brien Lake to the area west of Rush Lake; the fault slice is at least 130 m wide in the west but thins to between 28 and 65 m in the centre, east of Osis Lake. Turbidites in this fault-bounded



Data-point error ellipses are 2σ

***Figure GS-17-11:** Concordia plot of U-Pb zircon ages from metasedimentary rocks of the Booster Lake and Flanders Lake formations, obtained by laser-ablation multicollector inductively coupled plasma mass spectrometry (LA-MC-ICP-MS).*

unit consist of cyclic greywacke-siltstone beds that display graded bedding and local flame structures, scour and parallel lamination. Stratabound, elongate cordierite porphyroblasts (1–2 cm long) occur sporadically, especially at the north margin of the fault slice. Bedding trends in the unit vary from west-northwest (concordant) to northeast, highly discordant with the inferred bounding faults (Figure GS-17-3); thus, emplacement of the structural inlier postdated at least one early deformation event. A smaller turbidite fault slice occurs parallel to and approximately 275 m north of the first unit, in the area east of Osis Lake. The second unit is at least 40 m wide, but its lateral extent has not been determined.

Winnipeg River area

A belt of volcanosedimentary rocks, which extends along the Winnipeg River from northern Eaglenest Lake

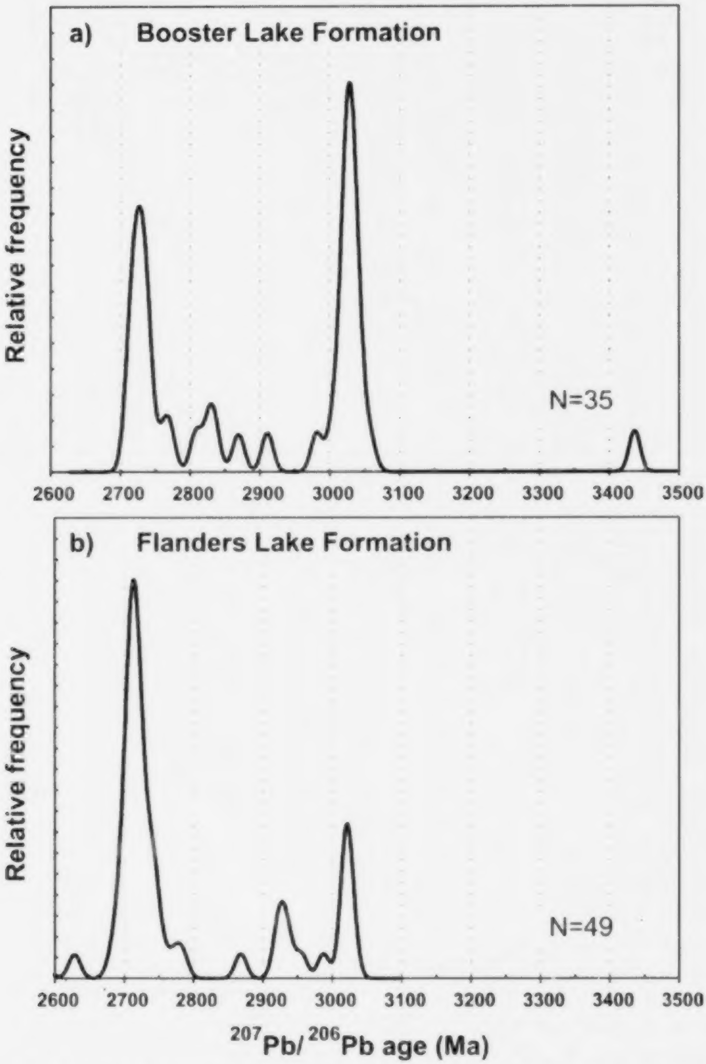


Figure GS-17-12: *Relative frequency distribution diagrams for U-Pb zircon ages from metasedimentary rocks of the Booster Lake and Flanders Lake formations obtained by laser-ablation multi-collector inductively coupled plasma mass spectrometry (LA-MC-ICP-MS). 'Relative frequency distribution' shows the frequency of each class as a part or a fraction of the total frequency for the entire distribution.*

to Lamprey Rapids (formerly know as Lamprey Falls), is separated from the 'main' BRB by a younger granitoid intrusion south of Birse Lake (Figures GS-17-2, -13). The belt at the Winnipeg River is juxtaposed along an inferred fault against rocks of the 'main' BRB in the area southeast of Ryerson Lake, close to the Manitoba–Ontario provincial boundary. The Winnipeg River Belt is bounded to the south by granitoid rocks of the Winnipeg River Domain.

The supracrustal belt at Winnipeg River consists mainly of aphyric pillowed basalt and related gabbro of the Lamprey Falls Formation and a subsidiary unit of greywacke and siltstone (Eaglenest Lake Formation) that is interpreted to be in fault contact with the Lamprey Falls Formation (Cerny et al., 1981). The mafic volcanic sequence is predominantly north facing, but local top reversals in the west part of the belt indicate the presence of a major fold structure. The fine-grained greywacke and siltstone of the Eaglenest Lake Formation in the east part of the belt young to the south and, for this reason, are interpreted to be in fault contact with the Lamprey Falls basalt immediately to the north. In the west part of the belt, a poorly exposed felsic breccia unit on the south shore of the Winnipeg River is interpreted as fault bounded and is provisionally assigned to the arc volcanic assemblage (Table GS-17-1); however, there are insufficient data to clearly establish the stratigraphic significance of this unit.

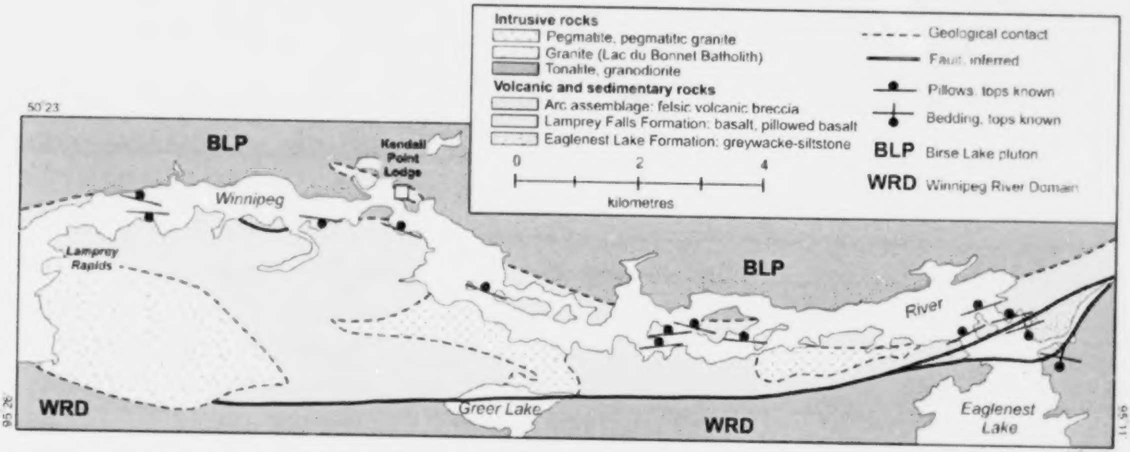

Intrusive rocks
Pegmatite, pegmatitic granite
Granite (Lac du Bonnet Batholith)
Tonalite, granodiorite
Volcanic and sedimentary rocks
Arc assemblage: felsic volcanic breccia
Lamprey Falls Formation: basalt, pillowed basalt
Eaglenest Lake Formation: greywacke-siltstone
0
2
4
kilometres
Geological contact
Fault, inferred
Pillows, tops known
Bedding, tops known
BLP Birse Lake pluton
WRD Winnipeg River Domain
50°23
BLP
Kendall Point Lodge
Winnipeg
Lamprey Rapids
BLP
River
95°26
WRD
Greer Lake
WRD
Eaglenest Lake
95°11
50°20.5

Figure GS-17-13: Geological map of the Winnipeg River area.

Lamprey Falls Formation

Basalt, aphyric, mostly pillowed; related amphibolite and mafic gneiss

The Lamprey Falls Formation in the Winnipeg River area is similar to the MORB-type, pillowed flow sequence, assumed to be stratigraphically equivalent, at the north margin of the BRB (Figure GS-17-2). In the Winnipeg River area, this formation is approximately 2.5 km wide and extends south to Greer Lake (Figure GS-17-13). The basalt is aphyric and commonly quartz amygdaloidal, locally with amygdule-rich domains confined to the upper margins of pillows. Pillows, typically 0.5 to 1 m in size (up to 1 m by 5 m) are commonly undeformed and provide excellent top indicators (Figure GS-17-10e). Polygonal cooling fractures were observed in one flow in the west part of the belt. The fine-grained basaltic rocks are locally altered and recrystallized, resulting in coarser grained, polygonal hornblende-plagioclase domains within individual pillows (Figure GS-17-10f). Conspicuous garnet porphyroblasts (0.5–1.5 cm) occur sporadically and, in marginal parts of the formation close to granitoid rock contacts, the basalt is recrystallized to very coarse grained garnet-hornblende-plagioclase gneiss with garnetite layers up to 0.5 m thick.

Chert, oxide-facies iron formation

Several exhalitive chert-magnetite formations occur within the Lamprey Falls basalt sequence along the south shore of the Winnipeg River. The most conspicuous of these is a 25 m wide unit that consists mainly of white-grey chert, finely laminated at 1–5 mm scale, with subordinate oxide-facies iron formation characterized by 0.5 to 3 cm thick layers of chert, chloritic amphibolite (±magnetite) and ankerite. This volcanic exhalitive unit displays widespread rusty-weathered surfaces that represent oxidized domains of secondary pyrite mineralization. An alteration zone, more than 40 m wide with pervasive pyrite-pyrrhotite-chalcopyrite mineralization, occurs immediately south of the chert and oxide-facies iron formation (*see* 'Economic considerations' section). The mineralized chert and iron formation unit was observed to extend laterally for over 0.5 km. Sporadic, minor (0.3–1.7 m thick) units of similar chert, associated with both magnetite laminae and sulphide mineralization, occur elsewhere within mafic volcanic flows in the central and western parts of the Lamprey Falls Formation. Some of these units are tectonically attenuated and discontinuous due to strike-parallel shearing. Elsewhere, a tectonically undeformed unit consists of discontinuous layers and highly irregular, lobate bodies that suggest synsedimentary incorporation of the chert into a contiguous basalt flow prior to cooling.

Arc volcanic assemblage

Felsic fragmental rocks

Felsic volcanic breccia, located approximately 2 km west of Kendall Point Lodge (Figure GS-17-13) trends east-west for over 600 m along the south shore of Winnipeg River and may extend farther west to Shatford Lake (Figure GS-17-2; Cerny et al., 1981). The fragmental unit is monolithic and contains pale grey felsic pebbles, cobbles and sporadic larger clasts (up to 35 cm by 18 cm) in a cream-weathering siliceous matrix. The breccia is moderately to strongly attenuated (fragment elongation ratios vary up to 15:1) and locally tectonically brecciated. Dark grey, elongate mafic rafts are interpreted as disrupted, early concordant diabase veins.

Eaglenest Lake Formation

Fine-grained greywacke and siltstone, interpreted as turbidite deposits (Eaglenest Lake Formation), occur at the south margin of the Lamprey Falls Formation in the north part of Eaglenest Lake (Figure GS-17-13). Whereas the north margin of the turbidite sequence is interpreted as fault bounded, the south margin is intruded by granitoid rocks of the Winnipeg River Domain to the south (Beakhouse, 1977). The turbidites are approximately 600 m thick and interpreted to be south facing, based on sporadic occurrences of graded beds, rare flame structures and rip-ups. The epiclastic sequence is characterized by finely laminated, pale grey feldspathic greywacke, dark green-grey siltstone and localized, conformable, altered and recrystallized zones of medium-grained hornblende and plagioclase. Garnet porphyroblasts and minor pyritic domains occur sporadically, and iron formation occurs close to the north margin of the section (Cerny et al., 1981).

The stratigraphic position of the Eaglenest Lake Formation is unknown. The apparent back-to-back relationship with north-facing Lamprey Falls basalt to the north supports the interpretation of a major fault between the two formations. The Eaglenest Lake turbidites are lithologically similar to epiclastic rocks assumed to be the basal stratigraphic unit of the arc assemblage at Bird Lake (Figure GS-17-9, unit 1E). If the Eaglenest Lake turbidites are, in fact, part of the arc assemblage, a younger age of deposition relative to the Lamprey Falls Formation is implied.

Economic considerations

Mineral showings were encountered in all parts of the BRB mapped in 2006, except for the turbidite sequence at Booster Lake. These mineral occurrences can be divided into the following three types: a) those associated with oxide-facies iron formation; b) those located at the lower and upper contacts of a 450 m thick basalt unit in the BRB south panel; and c) conformable mineral showings within basalt, rhyolite, felsic porphyry or fine-grained metasedimentary rocks. The most conspicuous mineralized zone of type (a) is located on the south shore of the Winnipeg River, where a 25 m wide unit of chert and oxide-facies iron formation with pyritic domains occurs within basalt of the Lamprey Falls Formation. A 40 m wide alteration zone south of the chert is characterized by pervasive pyrite-pyrrhotite-chalcopyrite mineralization; the hostrock in this mineralized zone appears to be basalt and/or siltstone. Massive sulphides occur in 1 to 2 cm wide veins and coarse disseminated aggregates (Table GS-17-2, mineralized samples (MS 1 and 2). The total 65 m width of surface mineralization is a minimum figure, because of a lack of outcrop to the south. Minor chert units elsewhere within the same volcanic flow section also contain pyritic mineralization (Table GS-17-2, MS 3).

Two mineralized zones, also coincident with oxide-facies iron formation, occur in the north panel of the BRB. At the first locality, close to the south shore of central Bird Lake, a 6 m wide section of thinly bedded chert and massive magnetite contains several rusty zones with base-metal mineralization (Table GS-17-2, MS 4). The iron formation (Figure GS-17-9, unit 4E) occurs in an inferred south-facing sequence between altered, carbonatized pillowed basalt to the north and garnet-cordierite-bearing metasiltstone to the south (Figure GS-17-8e). A narrow (1 m), mineralized magnetiferous zone also occurs at this locality, immediately south of the basalt unit (Table GS-17-2, MS 5). Mineralized rocks at the lakeshore approximately 1 km farther west (Table GS-17-2, MS 6) are interpreted as part of the same stratigraphic unit. The second mineralized iron formation (Figure GS-17-9, unit 6E) is located south of Bird Lake within or at the south (upper) margin of the felsic volcanic unit south of Provincial Road 315 (Gilbert, 2006). Several concordant zones of base-metal sulphide mineralization (Table GS-17-2, MS 7, 8 and 9) occur in the magnetiferous siltstone-chert member (Figure GS-17-8f), which is partly deformed and disrupted, resulting in localized fault breccia.

Contact-related mineralization (type (b) above) occurs sporadically at the south margin of the 450 m thick basaltic unit that extends along the north flank of the BRB south panel (Gilbert, 2006). At least three mineralized localities (Table GS-17-2, MS 10 and 11) occur over a strike length of 8 km along this contact (*see* 'Basalt, aphyric, mostly pillowed; related amphibolite and mafic gneiss' section). Localized pyritic mineralization also occurs at the north margin of this thick basalt unit (Table GS-17-2, MS 12).

Mineralization type (c) consists of conformable zones that occur within specific lithological units. Within the BRB south panel, both rhyolite and pillowed basalt flows locally contain minor (<1 m) zones of this type (Table GS-17-2, MS 13), and a 10 m wide mineralized zone (Table GS-17-2, MS 14) occurs in the central part of the south panel, associated with metasomatic alteration and a conspicuous aeromagnetic anomaly (*see* 'Alteration in felsic volcanic rocks' section). In the Winnipeg River area (Figure GS-17-13), a similar but minor zone of mineralization in fine-grained metasedimentary rocks of the Eaglenest Lake Formation was sampled for geochemical analysis (Table GS-17-2, MS 15). Farther west, at a locality on the north shore of the Winnipeg River, a 70 m thick felsic porphyry sill within basalt of the Lamprey Falls Formation contains a network of massive pyrite-pyrrhotite veins in the central part of the intrusion, associated with silicification and brittle deformation (Table GS-17-2, MS 16). The Lamprey Falls Formation in the west part of the BRB north panel contains a 16 m wide, Cu-Zn-Ni-Au-bearing unit (Gilbert, 2005). The section at this locality contains abundant gabbro sills that host Cr and PGE mineralization in conformable zones, which were prospected by Falconbridge Limited through the 1980s (Poplar Bay property; Assessment File 94609, Manitoba Science, Technology, Energy and Mines, Winnipeg). Significant Cr_2O_3 (up to 13% over 3 m), as well as

Table GS-17-2: Selected analytical data for mineralized rocks in the BRB.

Field sample no.	Mineralized sample no.	UTM Zone 14U, NAD 83		Au	Ag	Cu	Cd	Mo	Pb	Ni	Zn	As	Co	Cr	Sb	W
		Easting	Northing	(ppb)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)
32-06-0563-1	MS 1	337321	5580158	6	< 0.3	123	< 0.3	< 1	< 3	71	69	4.1	47	243	0.2	< 1
32-06-0563-10	MS 2	337321	5580158	< 2	< 0.3	123	< 0.3	< 1	< 3	146	58	1.5	39	259	0.4	< 1
32-06-0553-2	MS 3	339234	5580454	< 2	< 0.3	377	< 0.3	< 1	< 3	18	83	4.2	15	11	0.2	< 1
32-06-0633-18	MS 4	334375	5593693	< 2	< 0.3	94	< 0.3	< 1	6	38	74	< 0.5	11	59	0.5	< 1
32-06-0632-1	MS 5	334598	5593762	10	0.5	96	< 0.3	< 1	4	12	189	2.3	5	42	0.3	3
32-06-0654-5	MS 6	333169	5593512	64	20	6490	7.1	27	7	41	949	< 0.5	108	36	0.3	38
32-06-0229-1	MS 7	338124	5593313	< 2	< 0.3	46	< 0.3	< 1	20	10	75	11.3	3	20	2.3	< 1
32-06-0229-2	MS 8	338124	5593313	13	0.3	55	< 0.3	< 1	9	49	82	8.7	15	39	1.6	< 1
32-06-0256-2	MS 9	336351	5593106	3	< 0.3	19	< 0.3	< 1	< 3	14	78	1.8	7	45	0.3	< 1
32-06-0505-2	MS 10	336273	5588890	9	< 0.3	14	< 0.3	< 1	15	10	73	162	3	28	< 0.1	< 1
32-06-0412-2	MS 11	333604	5590071	18	1	36	0.3	6	13	70	77	19800	50	23	10.8	< 1
32-06-0491-1	MS 12	335961	5589181	< 2	0.5	114	< 0.3	9	14	16	118	7.8	21	12	0.6	73
32-06-0418-5	MS 13	333578	5589927	< 2	0.4	34	< 0.3	< 1	< 3	5	59	178	7	7	0.2	310
32-06-0388-9	MS 14	334898	5588724	< 2	2.7	34	< 0.3	< 1	48	2	139	4.9	< 1	< 2	< 0.1	< 1
32-06-0539-7	MS 15	343325	5580182	< 2	< 0.3	313	< 0.3	< 1	< 3	68	135	2	51	73	< 0.1	< 1
32-06-0576-2	MS 16	332770	5583002	< 2	0.4	40	< 0.3	< 1	10	34	23	15.7	58	29	0.3	< 1

Pt (up to 500 ppb) and Pd (1175 ppb), are reported in drill logs at this locality; surficial grab samples yielded up to 5000 ppb combined Pt+Pd.

The most prospective rock types for base-metal mineralization in the map area are MORB-type basalt of possible BABB affiliation (e.g., Lamprey Falls Formation at the Winnipeg River; Table GS-17-2, MS 1, MS 2 and MS 3). In the case of the Lamprey Falls Formation at the BRB north margin, there is also potential for magmatic mineralization associated with gabbroic intrusions along strike from, and probably related to, the Bird River Sill, analogous to the above-described mineral deposit at the Poplar Bay property. Oxide-facies iron formation within volcanic rocks of inferred juvenile-arc affiliation is also prospective for both base-metal and Au mineralization (Table GS-17-2, MS 6).

Acknowledgments

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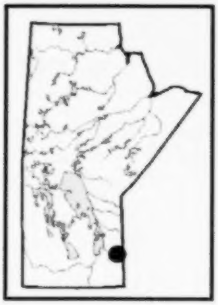
GS-18 Structural geology of the Bernic Lake area, Bird River greenstone belt, southeastern Manitoba (NTS 52L6): implications for rare element pegmatite emplacement

by P.D. Kremer[1] and S. Lin[1]



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Summary

In June of 2005, a two-year M.Sc. project was initiated to examine the structural geology of the Bernic Lake Formation and provide constraints on the emplacement of rare element pegmatite bodies that occur within it. The study is being completed at the University of Waterloo in co-operation with the Manitoba Geological Survey and the Tantalum Mining Corporation of Canada Ltd. (Tanco). Field components of the study included regional geological mapping (1:10 000 scale) of the Bernic Lake Formation around the Tanco mine, detailed geological mapping of exposed pegmatite occurrences within the Bernic Lake pegmatite group, examination of both production and exploration diamond-drill core from the Tanco mine, and underground geological mapping of the Tanco pegmatite.

Preliminary data from Bernic Lake suggest that pegmatite emplacement occurred in the late stages of D_1 deformation, a north-south compressive event manifested by large-scale isoclinal folding and a south-side-up sense of displacement in the area. Pegmatites of the Bernic Lake group show a clear spatial relationship to a thick high-strain zone that runs along the north shore of Bernic Lake and marks the axial plane of a synclinal structure. Where exposed, pegmatites east of the lake are intruded into metavolcanic and volcaniclastic rocks, are oriented either parallel or slightly oblique and crosscutting to regional deformation fabrics, and are locally deformed in a ductile manner (folded and/or boudinaged depending on their orientation relative the principle stresses). The Tanco pegmatite, hosted primarily in a polyphase, synvolcanic gabbro intrusion on the western margin of Bernic Lake, was emplaced along a subhorizontal conjugate fracture set.

Introduction

The Bird River greenstone belt is located in the Archean Superior Province of the Canadian Shield in southeastern Manitoba, approximately 100 km northeast of Winnipeg. It comprises metavolcanic and metasedimentary rocks and associated synvolcanic intrusions, which are bounded to the north by the English River Domain and to the south by the Winnipeg River Domain. Trueman (1980) subdivided the Bird River greenstone belt into six lithostratigraphic formations, termed the Eaglenest Lake Formation, Lamprey Falls Formation, Peterson Creek Formation, Bernic Lake Formation, Flanders Lake Formation and Booster Lake Formation. Detailed descriptions of each formation can be found in Trueman (1980), Cerny et al. (1981), Duguet et al. (GS-16, this volume) and Gilbert (GS-17, this volume).

The Bird River greenstone belt is also host, in part, to the Cat Lake and Winnipeg River pegmatite districts. Within the Winnipeg River district, the pegmatites have been separated into eight groups of spatially, mineralogically and geochemically related bodies. The Bernic Lake pegmatite group is clustered around Bernic Lake and includes the highly fractionated, rare element–bearing Tanco pegmatite, which is currently being mined for tantalum, cesium and lithium.

Results

General geology

An area of approximately 40 km^2, extending from the southern shoreline of Bernic Lake northward to the faulted contact of the Bernic Lake Formation and the Booster Lake Formation, was mapped at a scale of 1:10 000 during the summers of 2005 (Kremer, 2005a, b) and 2006 (Figure GS-18-1; Kremer and Lin, 2006).

Mafic volcanic rocks (basalt-andesite) form the most extensive unit in the map area. They occur primarily as pillowed and massive flows, reaching many tens to hundreds of metres in thickness. The basalt weathers dark greyish green to black and is generally very fine grained and aphyric, although feldspar-phyric occurrences are observed. Quartz±feldspar amygdules up to 3 cm across and epidote alteration are common in pillowed flows. A moderately to very well developed schistosity occurs in all varieties of basalt. Primary features and pillow selvages are occasionally well preserved and, in places, suitable for determination of younging direction, although they often display a very high degree of stretching (aspect ratios up to 100:1) or are completely obliterated by the effects of deformation and recrystallization, with only minor amounts of recognizable relict selvage material (Figure GS-18-2).

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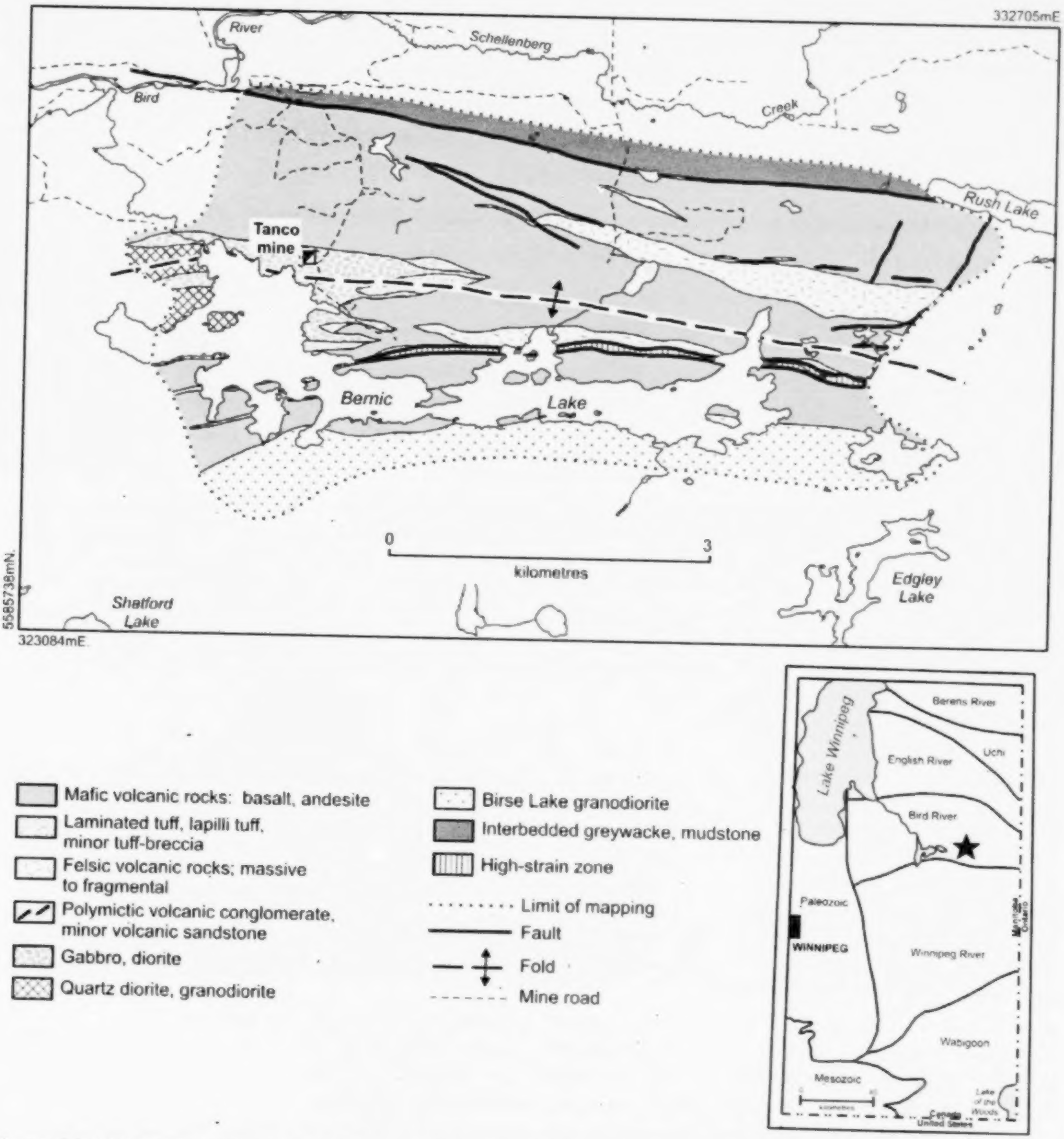
332705mE
5591569mN
River
Schellenberg
Bird
Creek
Rush Lake
Tanco mine
Bernic
Lake
0
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Edgley Lake
Shatford Lake
5585738mN
323084mE
Mafic volcanic rocks: basalt, andesite
Laminated tuff, lapilli tuff, minor tuff-breccia
Felsic volcanic rocks; massive to fragmental
Polymictic volcanic conglomerate, minor volcanic sandstone
Gabbro, diorite
Quartz diorite, granodiorite
Birse Lake granodiorite
Interbedded greywacke, mudstone
High-strain zone
Limit of mapping
Fault
Fold
Mine road
Lake Winnipeg
Berens River
Uchi
English River
Bird River
Paleozoic
WINNIPEG
Winnipeg River
Manitoba
Ontario
Wabigoon
Mesozoic
Lake of the Woods
Canada
United States

Figure GS-18-1: Preliminary map of the Bernic Lake area around the Tanco mine, Bird River greenstone belt, southeastern Manitoba PMAP2006-9 (Kremer and Lin, 2006).

Massive to fragmental, quartz- and feldspar-phyric dacite defines a map unit that is thickest to the northeast of Bernic Lake and thins toward the west. The dacite typically weathers buff grey to white and contains up to 15% euhedral to subhedral quartz and feldspar phenocrysts. Schistosity is weakly to moderately developed in the dacite unit. Clasts in the fragmental variety show flattening on horizontal outcrop surfaces and display a prominent down-dip stretching lineation on vertical outcrop surfaces.

Thin lenses of volcanic conglomerate, volcanic sandstone, tuff and lapilli tuff, with minor tuff-breccia, occur sporadically throughout the volcanic pile. These rocks, which range up to approximately 50 m in thickness, are not laterally extensive and can rarely be traced along strike for more than a few hundred metres. Primary bedding features are identified in some locations and are consistent with top determinations derived from pillow basalt flows (Figure GS-18-3). The volcanic conglomerate consists predominantly of moderately sorted clasts

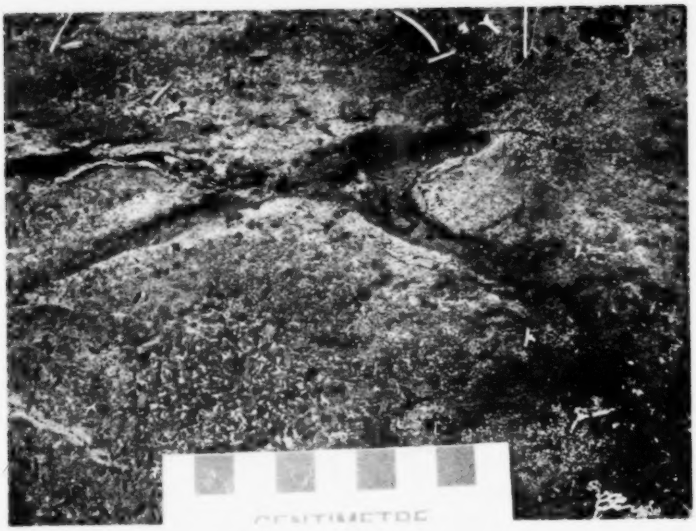

Figure GS-18-2: *Strongly recrystallized pillow basalt, east of Bernic Lake.*

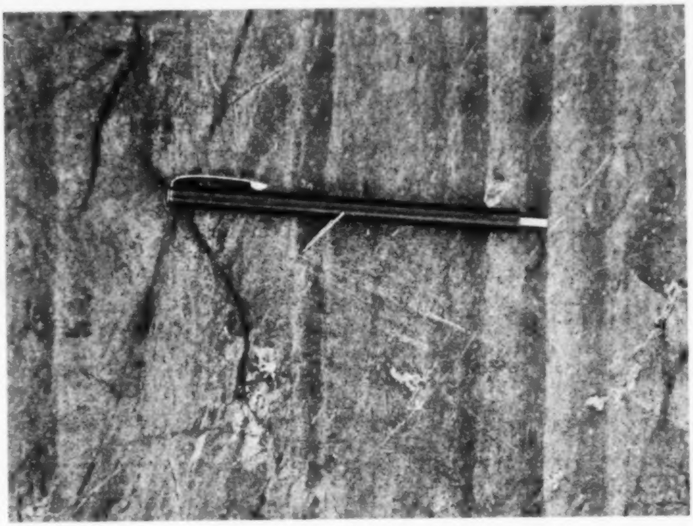

Figure GS-18-3: *Normal-graded beds in volcanic sandstone, indicating tops to the north (magnet for scale points north), east of the Tanco mine.*

of felsic volcanic rock (dacite) within a fine-grained, typically mafic, schistose matrix; fragments of basalt are rare (Figure GS-18-4).

A medium- to coarse-grained, polyphase, synvolcanic intrusion occurs on the western portion of Bernic Lake around the Tanco minesite. The intrusion is composed of gabbro, diorite, quartz diorite and granodiorite. Contact relationships with the host volcanic rocks are sharp and, for the most part, parallel with the subvertical, east trend of major lithological contacts, although some crosscutting relationships occur. Evidence of intrusion brecciation of early phases (gabbro-diorite) is observed in many locations on Bernic Lake, in locations where weakly to moderately resorbed inclusions of gabbro-diorite are hosted within a granodioritic matrix (Figure GS-18-5). On the southern margin of the intrusion, however, these relationships become spurious, and evidence would suggest that the mafic and felsic phases are comagmatic. The three-dimensional expression of this body is poorly constrained; the deepest vertical diamond-drill holes from the Tanco mine failed to pierce the lower contact.

The southern portion of Bernic Lake is underlain by a large intrusion, known as the Birse Lake granodiorite, that extends southward to the Winnipeg River. It is very homogeneous in shoreline outcrops on Bernic Lake and contains abundant feldspar phenocrysts up to 3 cm in length. Large xenoliths of basalt country rock, up to 5 m across, occur near the margins.

Hostrock structural geology and kinematics

The prominent structural feature within the Bird River greenstone belt is a large synform located in the northeastern portion of the belt. Map units in the area around Bernic Lake trend west to west-northwest, dip subvertically, and define, in part, the southern flank of this

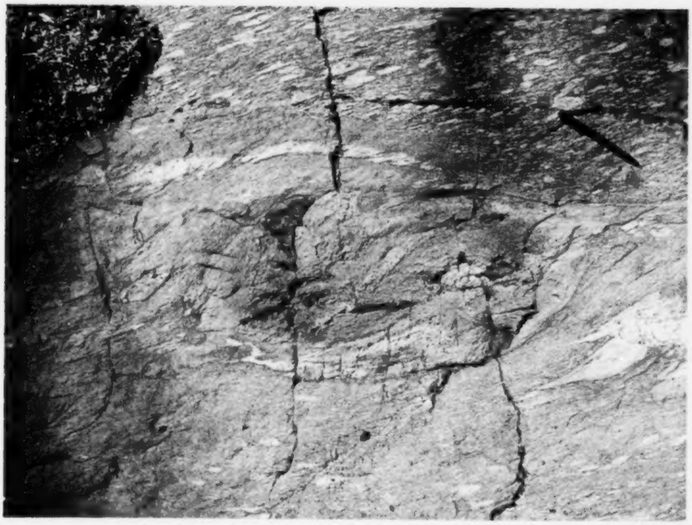

Figure GS-18-4: *Large basalt clast in bedded volcanic conglomerate, northeast of Bernic Lake. Asymmetric tails on clast indicate dextral shear.*

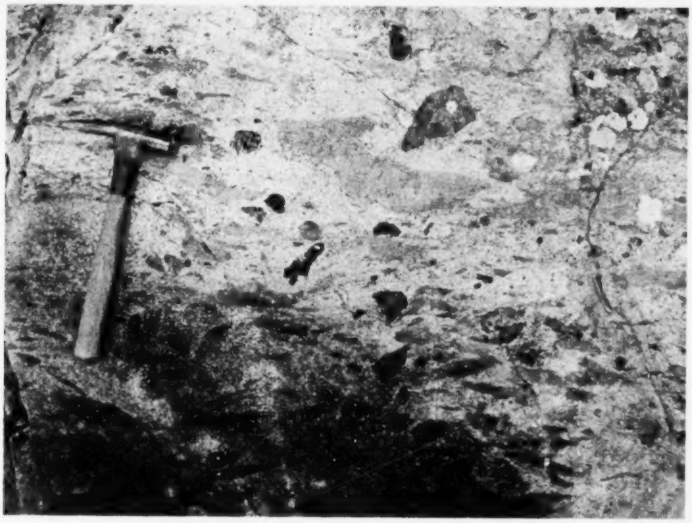

Figure GS-18-5: *Igneous intrusion breccia, western Bernic Lake.*

large fold structure. Mapping has identified three distinct generations of deformation in the Bernic Lake Formation, which are discussed below.

D_1 deformation

Structures associated with the first phase of deformation are ubiquitous throughout the entire map area. This deformation is manifested as a pervasive, closely spaced, layer-parallel, biotite-amphibole±chlorite schistosity (S_1) that is present to varying degrees in all rock types (with the exception of certain intrusive bodies). The S_1 schistosity trends between 80 and 120° and generally dips steeply to the south (Figure GS-18-6). A strong down-dip stretching lineation is defined by elongate fragments in dacite and volcanic conglomerate. Locally, a hornblende mineral lineation is parallel to the stretching lineation. Bedrock outcrops around Bernic Lake define an anticline-syncline pair, which is interpreted to be associated with this deformation. The identification of these folds is difficult owing to poor outcrop exposure along their axial traces and the fact that drag and parasitic folds are virtually absent within the stratigraphy. Nevertheless, consistent reversals in younging criteria across the map area, as well as a general unit repetition, support this interpretation. Where good exposure does exist, very tight to isoclinal, moderately to steeply west- to west-southwest-plunging folds are observed (Figure GS-18-7). The hinge of the synclinal structure lies within and is completely overprinted by a high-strain zone along the northern shore of Bernic Lake.

High-strain and shear zones belonging to the D_1 deformation occur throughout the map area parallel to the S_1 schistosity. Shear zones range from discreet zones no more than 5 cm in width to major structures, the most prominent of which is a high-strain zone observed along the northern shoreline of Bernic Lake and ranges

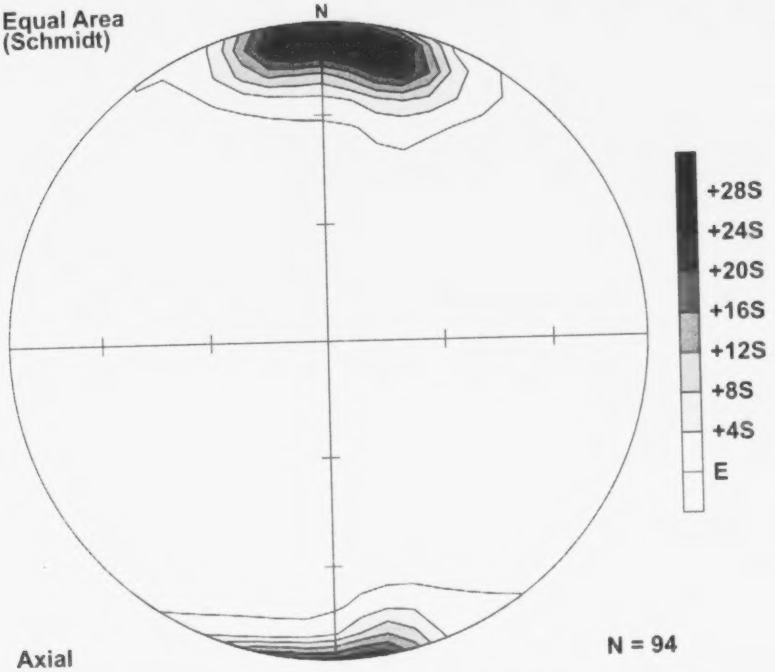

Figure GS-18-6: Equal-area, lower-hemisphere stereographic projection of D_1 structural elements in the Bernic Lake Formation.

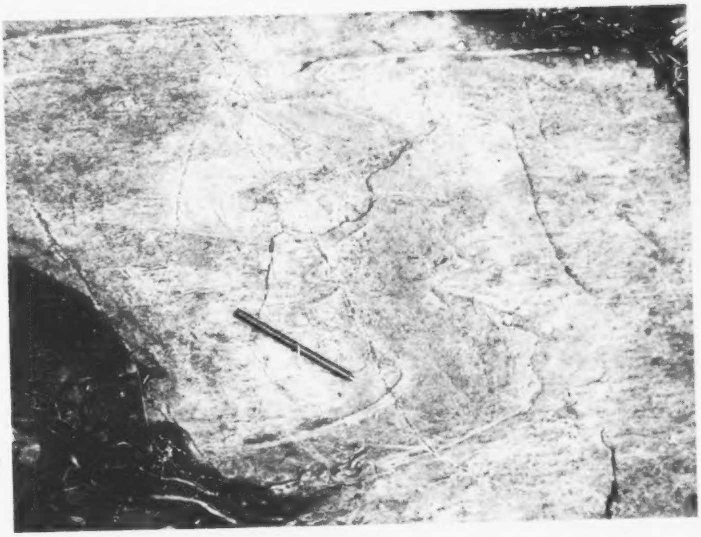

Figure GS-18-7: Partially attenuated m-fold along axial trace of F_1 anticlinal structure, power line north of Bernic Lake.

between 100 and 200 m thick. Primary features are rarely preserved, although the available evidence suggests that the zone represents the tectonized contact between basalt to the south and volcaniclastic rocks to the north. Narrow zones of protomylonite are common throughout the Birse Lake granodiorite, especially near the northern contact. Sense-of-shear criteria are abundant and include asymmetric boudins, asymmetric flattened clasts and asymmetric tails around garnet porphyroblasts. Shear criteria, when viewed in vertical outcrop surfaces parallel to the stretching lineation, consistently show a south-side-up sense of displacement. Minor dextral strike-slip displacement is seen in small-scale z-asymmetric dragfolds and asymmetric tails on horizontal surfaces (Figure GS-18-8).

D_2 deformation

Structures of the D_2 deformation observed in the Bernic Lake area consist of a locally developed, spaced

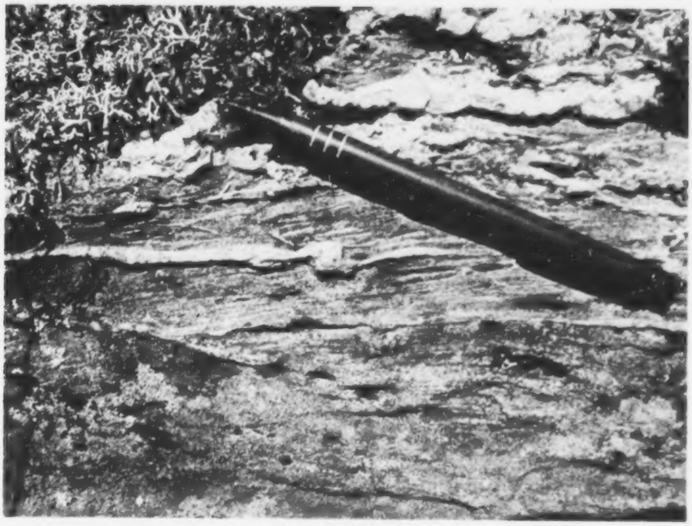

Figure GS-18-8: Small-scale, z-asymmetrically folded quartz vein in D$_1$ high-strain zone, east of Bernic Lake.

fracture cleavage that is most evident towards the southern portion of the map area, where it is consistently oriented 15 to 30° counter-clockwise to the S$_1$ schistosity. Opposing vergence was not noted, although this structural feature was not found on the south-facing limb of the anticline-syncline pair. This cleavage is axial planar to small, upright, gentle to open folds that are visible on vertical outcrop surfaces and affect narrow quartzofeldspathic veins that crosscut S$_1$. Numerous narrow gabbroic dikes are intruded parallel to this feature (Figure GS-18-9). It is likely that reactivation of D$_1$ structures during D$_2$ is responsible for some overprinting sinistral strike-slip movement observed along D$_1$ structural planes.

D$_3$ deformation

This late, brittle event is manifested by large north- or northeast-trending lineaments that cut across the map area. Displacement across these large-scale structures was never noted. On subsidiary parallel structures, however, a component of sinistral strike-slip movement exists. At least two conjugate fracture sets are present within the entire stratigraphy, and are tentatively associated with this late event. In some instances, intense silicification, albitization and potassium alteration are present along these fracture sets, possibly owing to degassing from buried pegmatites. Structural measurements of brittle fractures, taken over the course of fieldwork, have various orientations; stereographic analysis is underway.

Pegmatite structure

Pegmatites within the map area typically have very limited surficial expression and occur primarily within two areas. Around the Tanco mine, pegmatites are hosted

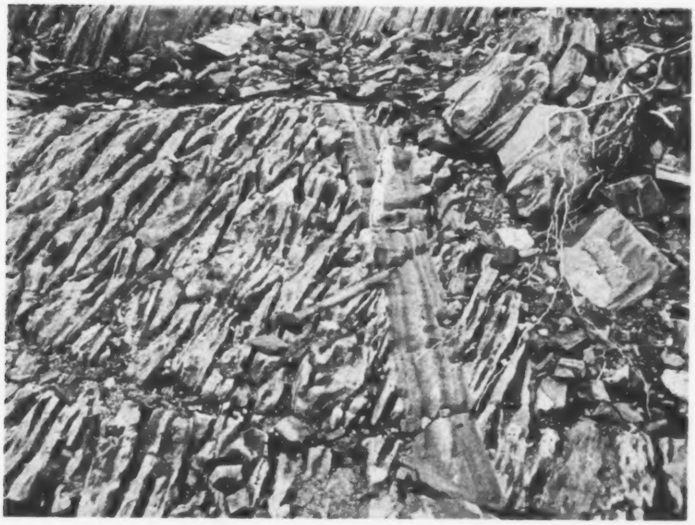

Figure GS-18-9: Fine-grained composite dike intruding pillow basalt, northeast of Bernic Lake. Pillows are stretched 110° (S$_1$) and dike is oriented parallel to overprinting cleavage (S$_2$) and trends 85°.

in gabbro-diorite or in metavolcanic rocks. These pegmatites have very sharp, straight contacts with the hostrocks and are generally tabular bodies with shallow to moderate dips. Where well exposed, they are oriented slightly oblique to, and crosscut, the pervasive schistosity within the volcanic rocks. The Tanco pegmatite is hosted largely within gabbro-diorite and is a doubly dipping body that was emplaced along a prominent conjugate fracture set.

Numerous pegmatites that occur east of Bernic Lake show a strong spatial association with the high-strain zone north of the lake. These pegmatites are deformed in a ductile manner within a north-south compressive regime (Figure GS-18-10). Folds and boudins are common, although the pegmatites retain many features of passive crystallization. These pegmatites are interpreted to be emplaced in dilatant zones during the late stages of D_1 deformation. Many of the other pegmatite groups and pegmatitic granite bodies within the Bird River greenstone belt are also emplaced along similar structures, and it is likely that large fault zones acted as conduits through which the late-stage granitic magma ascended.

Discussion

Pegmatites east of Bernic Lake show evidence of ductile deformation that has not been described in the Tanco pegmatite, although mineralogical and geochemical studies indicate that they are genetically related (Cerny and Trueman, 1977; Lenton, 1979; Cerny et al., 1981). Geochronological samples from representative pegmatites in each location were collected and are awaiting analysis to further constrain the relationship between deformed and undeformed pegmatites within the Bernic Lake Formation. Two possibilities seem feasible:

- Multiple generations of pegmatite emplacement may have occurred, whereby late D_1 pegmatite emplacement into ductile dilatant zones was followed by the emplacement of shallowly dipping tabular pegmatites (Tanco, Buck) along late fracture sets associated with D_3 deformation.
- If the analytical data indicate identical ages for pegmatites with different structural characteristics, then it may be a function of rheological contrasts between respective hostrocks (gabbro-diorite versus sheared metavolcanic rocks) that are responsible for the different emplacement styles and mechanisms.

Geochemical and geochronological analyses of the volcanic stratigraphy are currently underway and data are pending. Furthermore, the emplacement history of certain pegmatite occurrences will be further examined by U-Pb geochronology and by Ar-Ar dating of various minerals, extending from the pegmatite into the wallrock. The former will determine whether all pegmatites of the Bernic Lake group are of identical age, while the latter should help to constrain the P-T conditions at the time of emplacement. Microstructural analysis on numerous oriented thin sections is still underway, as is detailed stereographic analysis of late brittle fractures.

Economic considerations

The Tanco pegmatite is a world-class ore deposit that is currently being mined for tantalum, cesium and lithium. Exploration drillholes focused around geochemical anomalies in soil have identified numerous occurrences of rare element pegmatites, although none of them have the dimensions of the Tanco body (approximately 1400 m long by 600 m wide by 100 m deep). The tendency of pegmatites within the Bernic Lake Formation to be spatially associated with a large shear zone suggests that the shear zone may have acted as a plane of weakness within the stratigraphy, along which magma ascended through the crust. If the fracture-hosted, highly fractionated Tanco pegmatite is shown to be coeval with deformed

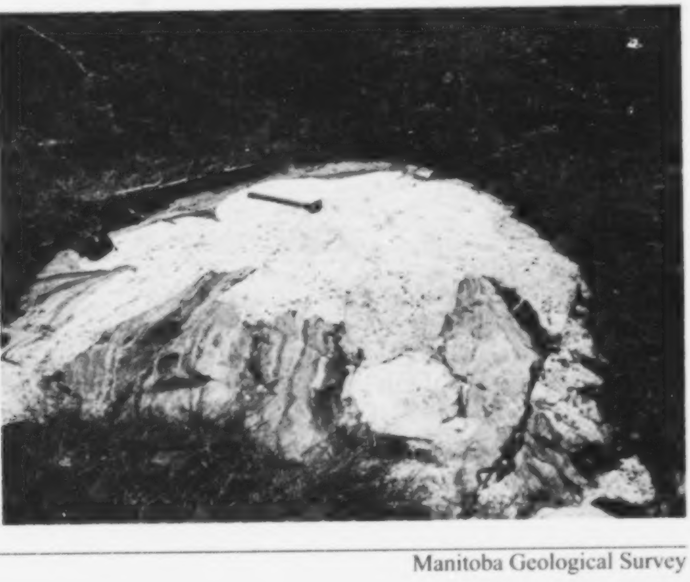

Figure GS-18-10: *Pegmatite displaying ductile deformation, east of Bernic Lake.*

pegmatites east of the lake that record the final increments of D_1 strain, then large-scale dilatant zones associated with this structure become of interest with regards to potential locations for the accumulation and crystallization of rare element–bearing pegmatitic fluids.

Acknowledgments

The author would like to thank B. Foster, K. Lewis and L. Osadchuk for their capable and enthusiastic assistance throughout the course of the field season, as well as M. Duguet and C. Mealin for sharing insights from their respective projects. C. Galeschuk, P. Vanstone and S. Moran from the Tanco mine are thanked for their support throughout the summer and for sharing their time, opinions and ideas. The project would not be possible without the continued logistical support, assistance and encouragement of the Manitoba Geological Survey.

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GS-19

Geological investigations in the Bird River Sill, southeastern Manitoba (part of NTS 52L5): geology and preliminary geochemical results

by C.A. Mealin[1]

Mealin, C.A. 2006: Geological investigations in the Bird River Sill, southeastern Manitoba (part of NTS 52L5): geology and preliminary geochemical results; *in* Report of Activities 2006, Manitoba Science, Technology, Energy and Mines, Manitoba Geological Survey, p. 214–225.

Summary

In 2005, this study was initiated to examine the Bird River Sill (BRS), a mafic-ultramafic layered intrusion located in the Bird River greenstone belt in southeastern Manitoba. The BRS is currently an exploration target for Ni-Cu–platinum group element (PGE) deposits and, in the past, hosted two Ni-Cu mines (Maskwa West and Dumbarton mines).

Nickel-copper mineralization on the western half of the BRS consists primarily of disseminated to blebby pyrrhotite+chalcopyrite and is present in the ultramafic series of the Chrome and Page properties and the mafic series of the Wards property. During this study, several new sulphide-bearing localities in both the ultramafic and mafic units of the sill have been identified. In addition, the geological contacts of the sill have been further constrained and the structural setting of the sill is being redefined (this study and Duguet et al., GS-16, this volume).

This report includes new geological data for the BRS and preliminary geochemical results.

Introduction

The Bird River sill (BRS) is a mafic-ultramafic intrusion located in the southern part of the Bird River Domain, approximately 120 km northeast of Winnipeg in southeastern Manitoba. Since the 1920s, the sill has been known to contain Ni, Cu and Cr mineralization, and has hosted two Ni-Cu mines, the Dumbarton mine (from 1969 to 1974) and the Maskwa West mine (from 1974 to 1976). The presence of platinum group elements (PGE) was discovered in the early 1980s by Theyer (1985).

Numerous studies have produced different theories over the years on the emplacement of the BRS and its inherent Ni-Cu-PGE and Cr mineralization. The sill was considered by Bateman (1943) to be the result of two different magma pulses: the first being of ultramafic composition and the second of mafic composition. Osborne (1949), the first to describe the magmatic lithology of the sill in detail, proposed a complex multi-injection theory. Juhas (1973), Trueman (1971) and Scoates (1983) all suggested a single magmatic injection where the layering was formed by subsequent crystal fractionation and gravitational differentiation. Theyer (1985) identified unusual cooling conditions requiring several magma pulses and cast doubt on a single magmatic intrusion theory.

In 2005, this study was initiated to examine the controls on Ni-Cu-PGE mineralization and test the single versus multiple injection hypothesis to establish the relationship between mineralization and the magmatic history. Specific objectives include

- detailed mapping of the Chrome, Page, Peterson Block and National-Ledin properties (Figure GS-19-1);
- determination of the sulphur source for the Ni-Cu-PGE mineralization;
- delineation of the sill's sulphur saturation history;
- examination of the sill's magmatic history; and
- examination of the influence of crustal contamination/assimilation on the sill.

This report presents the geology of the western half of the sill and preliminary geochemical results.

Previous work

Between 1982 and 1984, P. Theyer and assistants sawed three semicontinuous sampling sections (western, central and eastern cuts) across the Chrome property in the BRS. The western and eastern cuts crosscut the ultramafic portion and the central cut the gabbroic portion of the sill. These provide a nearly continuous channel sample and cross-section of the sill. Detailed geochemical analyses led to the identification of two PGE- and sulphide-enriched layers within the ultramafic unit (Theyer, 1985). Additional PGE-bearing layers were identified in the following years (Scoates et al., 1989).

Theyer (1985) defined several distinct igneous cycles based on remnant crystal morphology of olivine within the eastern and western cuts. The base of an idealized magmatic cycle is defined as a layer of fine-grained, tightly packed, lensoid-stage olivine that exhibits an abrupt lower contact with skeletal olivine. The remnant olivine textures exhibit a repeated progression from simple, ovoid crystal habits to increasingly complex dendritic crystals (Theyer, 1985).

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[1] University of Waterloo, Waterloo, Ontario N2L 3G1

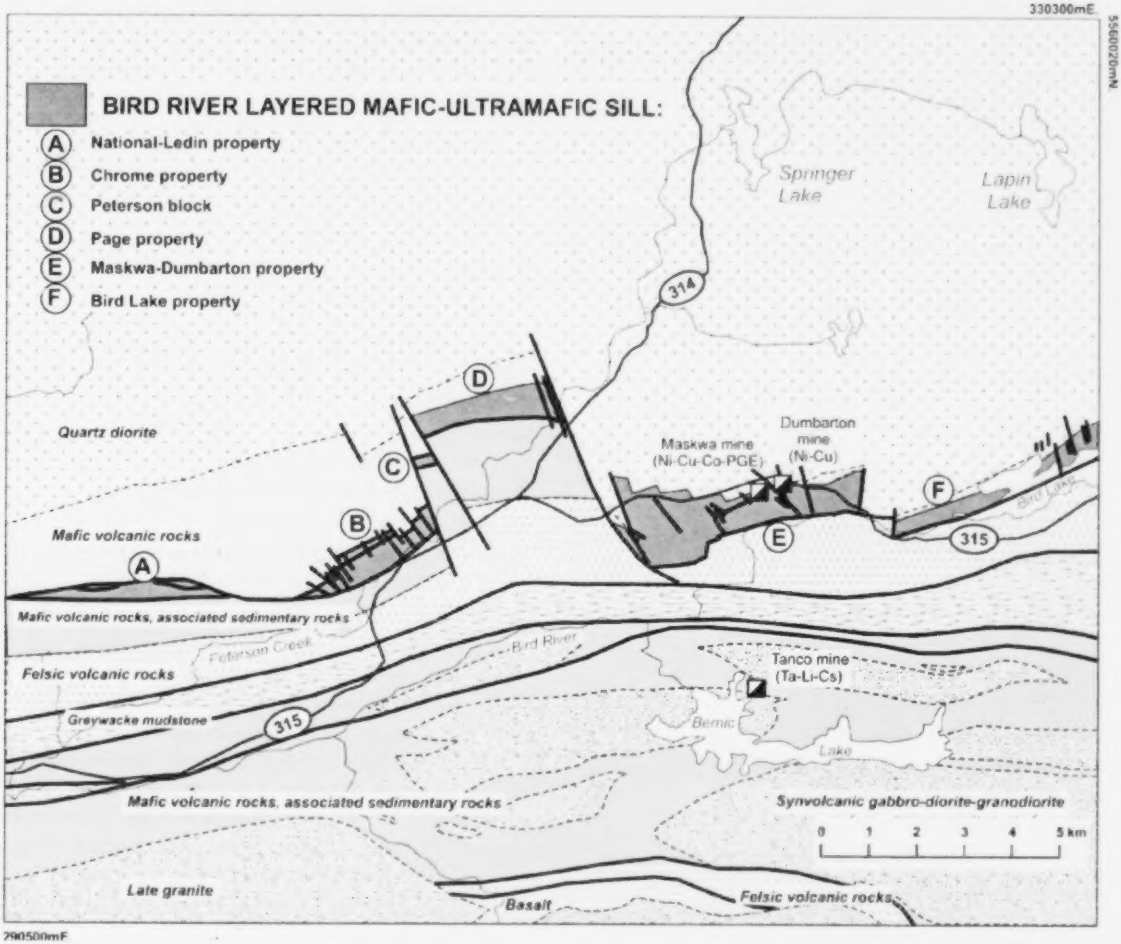
330300mE
5560020mN
BIRD RIVER LAYERED MAFIC-ULTRAMAFIC SILL:
Ⓐ National-Ledin property
Ⓑ Chrome property
Ⓒ Peterson block
Ⓓ Page property
Ⓔ Maskwa-Dumbarton property
Ⓕ Bird Lake property
Springer Lake
Lapin Lake
314
D
Quartz diorite
C
Dumbarton mine (Ni-Cu)
Maskwa mine (Ni-Cu-Co-PGE)
F
Bird Lake
B
E
315
Mafic volcanic rocks
A
Mafic volcanic rocks, associated sedimentary rocks
Peterson Creek
Bird River
Felsic volcanic rocks
Tanco mine (Ta-Li-Cs)
Greywacke mudstone
315
Bernic Lake
Mafic volcanic rocks, associated sedimentary rocks
Synvolcanic gabbro-diorite-granodiorite
0 1 2 3 4 5 km
Late granite
Basalt
Felsic volcanic rocks
5583000mN
290500mE

Figure GS-19-1: Location of the Bird River Sill (after Theyer et al., 2001).

Talkington et al. (1983) completed a study on platinum group mineral (PGM) inclusions in chromite from the Chrome property of the BRS. Platinum group mineral inclusions in chromite occur as discrete grains of laurite (Ru, Os, Ir)S_2, rutheniridosmine (Os, Ir, Ru alloy) and one PGE alloy containing 0.96 wt. % Rh (Talkington et al., 1983). Laurite grains contained up to 2.99 wt. % Pd, but no Pt was detected. All the chromite specimens collected contained inclusions of silicate minerals and hematite, but only samples from chromite seams contained PGM inclusions. Increasing oxygen fugacity by wallrock assimilation or new magma injection is thought to be the trigger for the chromite precipitation (Talkington et al., 1983).

Regional geology

The BRS intrudes the east-trending Bird River greenstone belt (BRGB), located in the southern portion of the Bird River Domain. The BRGB is in the Archean Superior Province of the Canadian Shield and is located in southeastern Manitoba. It is bounded to the north by the English River Domain and to the south by the Winnipeg River Domain.

The supracrustal rocks of the BRGB have been subdivided into six formations (Trueman, 1971; Cerny et al., 1981):

Eaglenest Lake Formation: volcaniclastic sedimentary rocks and mafic lavas

Lamprey Falls Formation: pillowed basalt with intercalated tuff and iron formation

Peterson Creek Formation: rhyolite flows, pyroclastic breccia, lapilli tuff, tuff and volcanic sandstone

Bernic Lake Formation: basalt, andesite, dacite, rhyolite, iron formation, conglomerate and sandstone

Flanders Lake Formation: polymictic conglomerate and metamorphosed lithic arenite

Booster Lake Formation: greywacke-mudstone turbidite, interbedded conglomerate and iron formation

Further descriptions can be found in Duguet et al. (GS-16, this volume).

Geology of the Bird River Sill

The BRS is a differentiated, layered, mafic-ultramafic sill that intrudes the Lamprey Falls Formation and is overlain by the Peterson Creek Formation. It trends easterly and is reported to be 2744.7 ±5.2 Ma (Wang, 1993). The sill has been metamorphosed to greenschist facies, and locally by contact metamorphism to lower amphibolite facies adjacent to granitic intrusions (Juhas, 1973). Primary textures are generally well preserved, although metamorphic minerals replace most of the original minerals (Theyer, 2002).

Mapping the western half of the BRS and immediate surrounding formations of the BRGB at a scale of 1:5000 was completed over the 2005 and 2006 summer field seasons. The final map (Mealin, 2006) is a compilation of this author's preliminary BRS map, Davies' (1952) BRGB map, Williamson's (1990) Chrome property maps, Duguet et al.'s (GS-16, this volume) BRGB map and interpretations from total field magnetic data (made available by Gossan Resources Ltd. and North American Palladium Ltd.).

Relationships between the Bird River Sill and country rock types

Lamprey Falls Formation

The BRS is hosted by the Lamprey Falls Formation. The intrusive contact is exposed in outcrops on the Chrome, Peterson Block and National-Ledin properties (Figure GS-19-2b). The formation comprises massive to pillowed basalt that ranges from aphyric to megacrystic. The pillowed basalt is generally moderately deformed and locally brecciated. Gilbert (2005) demonstrated that the basalt is geochemically akin to modern back-arc-basin basalt: the extended-element plot is almost flat, with rare earth element values similar to mid-ocean-ridge basalt (MORB; Gilbert, 2005).

Several gossanous shear zones are present north of the Chrome, Page and Peterson Block properties. The shear zones are mineralized with remobilized chalcopyrite, pyrite and pyrrhotite. Further petrographic study is ongoing and geochemical analyses are pending.

Davies (1952) mapped numerous east-trending gabbroic intrusions and one granitic intrusion in the Lamprey Falls Formation north of the BRS. The gabbro is massive and relatively undeformed. These intrusions were mapped by Juhas (1973) as being part of the BRS, but they have since been treated as separate from the sill and are completely omitted from later compilations (Cerny et al., 1981). The nature of the gabbroic intrusions, their age and their relation to the sill are currently unknown, but they have been sampled for further investigation.

Peterson Creek Formation

The BRS is overlain by the Peterson Creek Formation. The formation overlying the BRS has historically been interpreted to be part of the Bernic Lake Formation, but recent work by Duguet et al. (GS-16, this volume) has redefined the formations in this part of the belt.

The Peterson Creek Formation comprises metavolcanic and metasedimentary sequences. The volcanic rocks include rhyolite, lapilli tuff and tuff. The sedimentary rocks comprise greywacke turbidite, chert, mafic clast conglomerate and a polymictic conglomerate. The polymictic conglomerate was identified overlying the sill south of the Chrome, Peterson block and National-Ledin properties. This conglomerate contains gabbroic clasts that are believed to be from the mafic unit of the BRS. Therefore, the contact between the Peterson Creek Formation and the BRS likely represents an unconformity.

Maskwa Lake Batholith

The Maskwa Lake batholith is a large granitoid intrusion that intrudes the northern margin of the BRGB and is observed to intrude the BRS at the eastern edge of

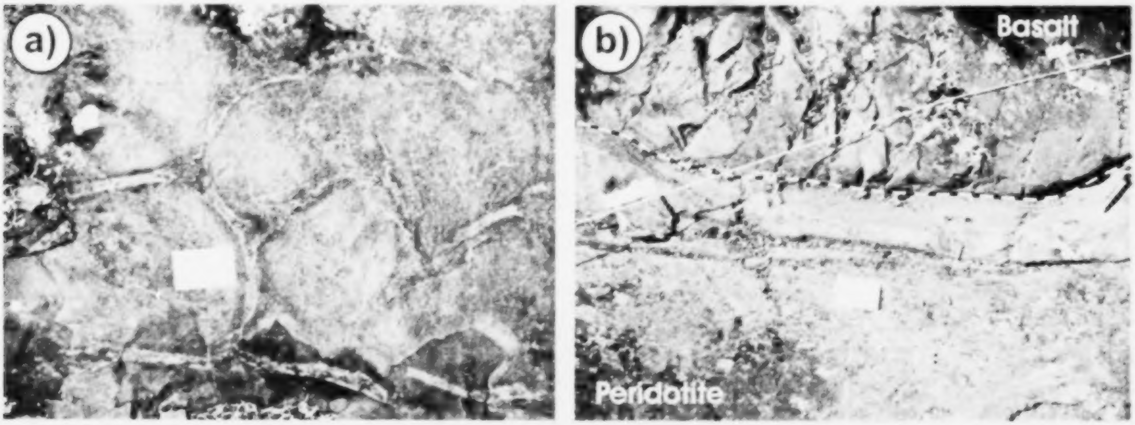

Figure GS-19-2: *Pillowed basalt, and* ***b)*** *intrusive contact of the Bird River Sill.*

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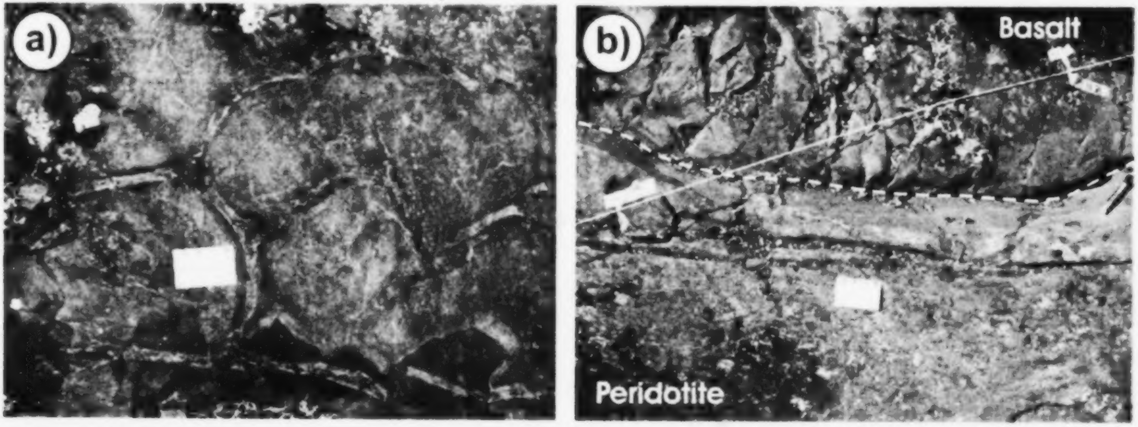

Figure GS-19-2: ***a)*** *Pillowed basalt, and* ***b)*** *intrusive contact of the Bird River Sill.*

the Page property. It comprises massive, coarse-grained granite, diorite and quartz diorite. The dominant rock type is quartz diorite. Contacts between the BRS and the Maskwa Batholith are not exposed. Further descriptions can be found in Cerny et al. (1981) and Duguet et al. (GS-16, this volume).

Bird River Sill

Stratigraphy

The BRS was originally subdivided into three magmatic series by Trueman (1971), based on the stratigraphy exposed at the Chrome property. The subdivisions, starting at the base, are the ultramafic series, the transition series, and the mafic series. The ultramafic series is absent on the Wards property but generally ranges from a few metres to 200 m thick on the Chrome, Page, Peterson Block and National-Ledin properties (Figure GS-19-3). The transition series was either absent or ranges from 1 to 5 m thick, and the mafic series ranges from 50 to 600 m thick.

Trueman's subdivision has since been expanded upon by Williamson (1990) and Scoates (1983), and is presented in column B of Figure GS-19-4 (Peck et al., 2002). The stratigraphy is based on extensive detailed mapping of the exposed central portion of the Chrome property. The current study observed and confirmed the previously defined stratigraphy and therefore focused on constraining the geological contacts of the BRS, the contact of the mafic and ultramafic units, and the location and full extent of chromite mineralization, as well as exploring for additional sulphide-bearing locations. The pegmatitic gabbro of the mafic series from the Chrome property was sampled this past summer for geochronological work.

The contact zone, reported by Trueman (1971) to contain plagioclase-bearing peridotite, also contains zones of pyroxenite that exhibit a rough, skeletal weathering. The chromitiferous zone on the Chrome property in general contains numerous straight, continuous, massive chromitite (>85% chromite) seams (Figure GS-19-5a), chromitiferous peridotite (<85% chromite) and 'disrupted' chromitite layers (Figure GS-19-5b). The chromite mineralization ranges from millimetres to metres in thickness.

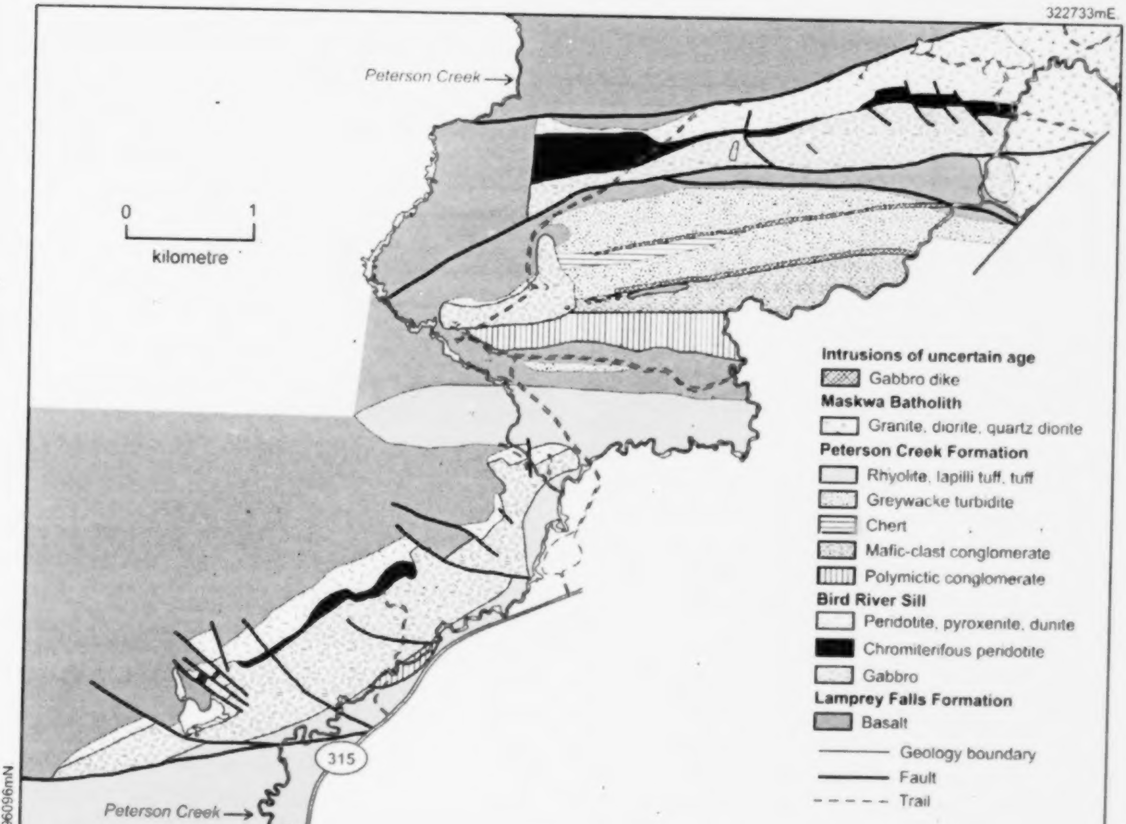
322733mE
5598096mN
Peterson Creek
0
1
kilometre
315
Peterson Creek
5596096mN
316390mE
Intrusions of uncertain age
Gabbro dike
Maskwa Batholith
Granite, diorite, quartz diorite
Peterson Creek Formation
Rhyolite, lapilli tuff, tuff
Greywacke turbidite
Chert
Mafic-clast conglomerate
Polymictic conglomerate
Bird River Sill
Peridotite, pyroxenite, dunite
Chromitiferous peridotite
Gabbro
Lamprey Falls Formation
Basalt
Geology boundary
Fault
Trail

Figure GS-19-3: *Geology of the Chrome, Page and Peterson Block properties, Bird River Sill.*

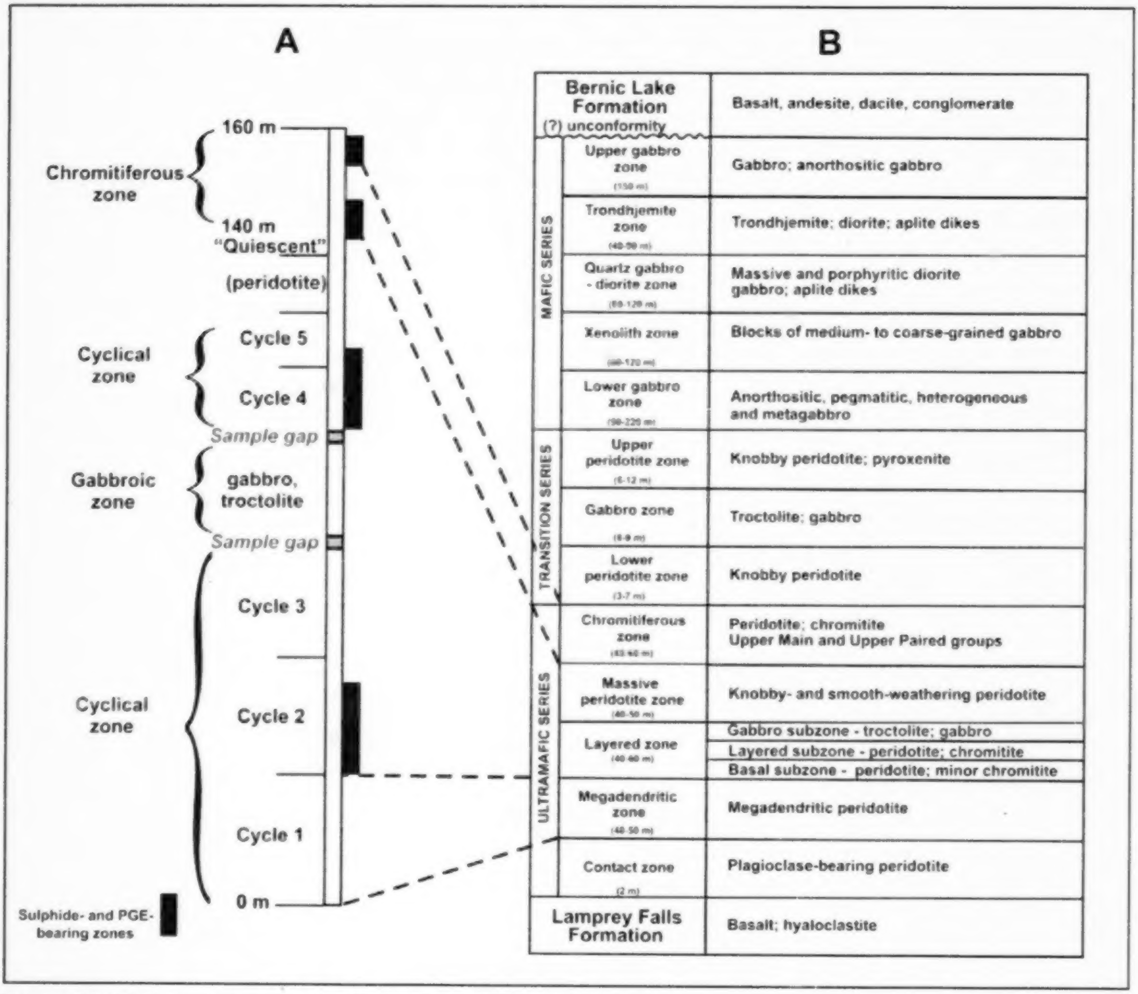
A
B
160 m
Chromitiferous zone
140 m
"Quiescent"
(peridotite)
Cyclical zone
Cycle 5
Cycle 4
Sample gap
Gabbroic zone
gabbro, troctolite
Sample gap
Cycle 3
Cyclical zone
Cycle 2
Cycle 1
0 m
Sulphide- and PGE-bearing zones
Bernic Lake Formation
(?) unconformity
Basalt, andesite, dacite, conglomerate
MAFIC SERIES
Upper gabbro zone
(150 m)
Gabbro; anorthositic gabbro
Trondhjemite zone
(40-90 m)
Trondhjemite; diorite; aplite dikes
Quartz gabbro - diorite zone
(80-120 m)
Massive and porphyritic diorite gabbro; aplite dikes
Xenolith zone
(60-120 m)
Blocks of medium- to coarse-grained gabbro
Lower gabbro zone
(90-220 m)
Anorthositic, pegmatitic, heterogeneous and metagabbro
TRANSITION SERIES
Upper peridotite zone
(6-12 m)
Knobby peridotite; pyroxenite
Gabbro zone
(6-9 m)
Troctolite; gabbro
Lower peridotite zone
(3-7 m)
Knobby peridotite
ULTRAMAFIC SERIES
Chromitiferous zone
(43-60 m)
Peridotite; chromitite
Upper Main and Upper Paired groups
Massive peridotite zone
(40-50 m)
Knobby- and smooth-weathering peridotite
Layered zone
(40-60 m)
Gabbro subzone - troctolite; gabbro
Layered subzone - peridotite; chromitite
Basal subzone - peridotite; minor chromitite
Megadendritic zone
(40-50 m)
Megadendritic peridotite
Contact zone
(2 m)
Plagioclase-bearing peridotite
Lamprey Falls Formation
Basalt; hyaloclastite

***Figure GS-19-4**: Stratigraphy of the Bird River Sill (Peck et al., 2002).*

Mineralization on the Page property is similar to that of the Chrome property but also contains chromitite and chromitiferous peridotite pebbles (Figure GS-19-5c). The pebbles increase in size (from a few millimetres to several centimetres), range from chromitite to chromitiferous peridotite and became increasing angular from the east end of the Page property towards the west. The pebbles and chromitite seams extend across the entire length of the Page property.

Massive chromite layers, up to 1 m wide, have also been identified at the Wards property (commonly referred to as the Coppermine Bay intrusion) by Theyer (1986) and, in contrast to other properties, are hosted in variably textured gabbro (Peck and Theyer, 1998). The BRS at the Wards property comprises a gabbroic intrusion with no ultramafic component.

A detailed 1:200 scale map of the chromite seams in the central portion of the Chrome property and a 1:100 scale sketch of the eastern exposure of the Page property chromitite, are presented by Williamson (1990) and Theyer et al. (2001), respectively.

Peck et al., (2002) proposed an alternative stratigraphy for the ultramafic series, incorporating five distinct igneous cycles and an upper quiescent zone (Figure GS-19-4, column A). The five cyclical layers coincide with the lower four subzones, and the quiescent zone corresponds to the chromitiferous zone.

It is important to note that the sill has been affected by greenschist-facies metamorphism and is intensely altered. In the ultramafic series, pyroxene is metamorphosed to amphibole (original amount is inferred to be proportional to the amphibole content; Theyer, 1990). Olivine is completely replaced, but original textures are preserved, as evidenced by pseudomorphs after olivine consisting of serpentine-tremolite-talc-carbonate±chlorite (Theyer, 1990). Accessory minerals include magnetite and ilmenite. The mafic series metamorphic assemblage consists of tremolite-clinoamphibole±clinozoisite±chlorite. Primary

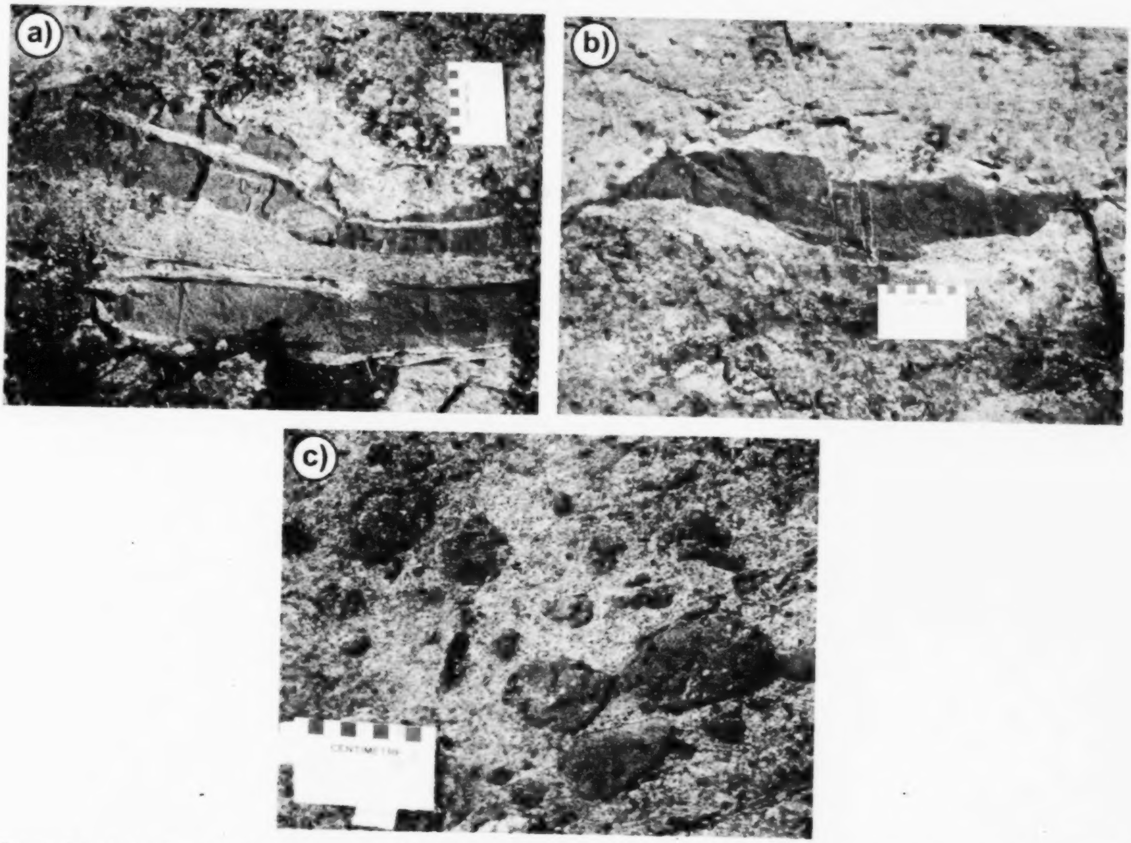

***Figure GS-19-5**: Three styles of chromite mineralization in the Bird River Sill: **a)** massive, continuous seams; **b)** disrupted seams, and **c)** chromitite pebbles.*

plagioclase has undergone varying degrees of sericite alteration throughout the Chrome property.

Mineralization

The BRS contains numerous sulphide-bearing zones enriched in Ni-Cu-PGE. The two most common sulphide minerals are pyrrhotite and chalcopyrite, which generally occur in the ultramafic unit of the BRS as fine disseminations. Sulphides are also present in the mafic unit of the BRS and underlying basalt of the Lamprey Falls Formation as remobilized material along shear zones.

As previously mentioned, four sulphide-bearing zones, enriched in Ni-Cu-PGE, were identified in the lower ultramafic series of the Chrome property (Figure GS-19-4) by Theyer (1985) and Scoates et al. (1989). The sulphides are associated with both the chromitiferous and massive peridotite zones and consist mainly of pyrrhotite-chalcopyrite ranging from fine disseminations to blebby disseminations to fracture coatings. In addition to the known four sulphide horizons, a possible fifth zone was identified this summer while channel sampling: millimetre-sized blebs of pyrrhotite and chalcopyrite were identified at the base of the Chrome property, approximately 1 m stratigraphically above the intrusive contact with the Lamprey Falls Formation. Assay results are pending.

Sulphide-bearing zones have also been identified on the Page property near the base of the chromitiferous zone by Theyer et al. (2001) and in drillholes penetrating the base of the sill. Styles of mineralization include massive pyrrhotite, semimassive net-textured pyrrhotite with minor chalcopyrite, millimetre- to centimetre-sized blebby disseminated pyrrhotite-chalcopyrite±millerite, disseminated pyrrhotite-chalcopyrite and pyrrhotite-chalcopyrite along fractures (Figure GS-19-6). The Page property mineralization is hosted in peridotite, pyroxenite and remobilized along fractures and quartz veins within the basalt of the Lamprey Falls Formation. Mineralization was also observed in quartz-feldspar porphyritic dykes; this occurrence is restricted to drillcore and was not observed on surface. Samples have been collected for further geochemical and petrographic study.

In contrast to the mineralized ultramafic series of the Chrome and Page properties, Peck and Theyer (1998) identified disseminated pyrrhotite and chalcopyrite sulphide mineralization in gabbro on the Wards property.

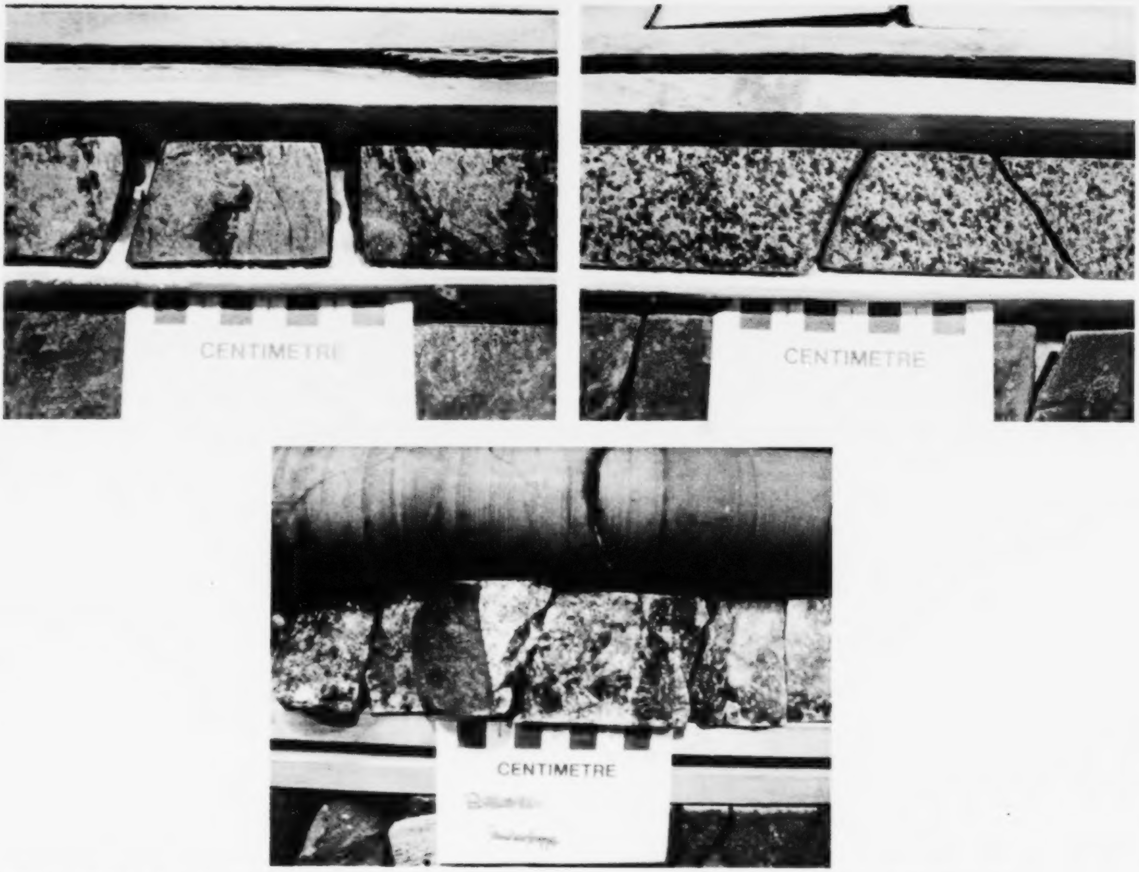

***Figure GS-19-6**: Styles of mineralization in the sulphide-bearing zones on the Page property, Bird River Sill.*

The sulphides, which occur within an anorthositic layer overlying a chromitiferous gabbroic layer, are reported to contain up to 1.3 ppm combined Pd+Pt (Theyer, 1986).

During the summer of 2005, sulphides were discovered associated with shear zones in the mafic series on the Chrome property. Specifically, disseminated chalcopyrite, pyrite and pyrrhotite, ranging from trace amounts to up to 5%, were observed. Twelve samples were collected whose assay results and locations are shown on Table GS-19-1 and Figure GS-19-7, respectively. Two of the samples collected from the upper portion of the mafic series, approximately 300 m stratigraphically above the ultramafic-mafic contact, contained significant PGE: 831 ppb Pt+Pd and 338 ppb Pt+Pd. This could imply that significant remobilization of PGE along shear zones has occurred in the BRS. Further geochemical analyses of samples from the mafic series of the Page property are pending.

Structure

Previous studies have treated the BRS as a continuous intrusion that was block faulted due to tectonism and granitoid intrusions (Davies, 1952). Displacements were believed to follow north-northwest-trending, steeply dipping faults that produced offsets of up to 1525 m (Bannatyne and Trueman, 1982). This summer's mapping, in conjunction with that of Duguet et al. (GS-16, this volume) and total field magnetics, failed to find any evidence to support the existence of these faults. Therefore, an alternative theory is proposed here for the segmentation of the BRS.

The properties of the BRS are best explained if there were initially separate magmatic intrusions, possibly from the same magma chamber (i.e., the BRS does not represent a single, continuous intrusion; Figure GS-19-1). Three east-west fault zones, each several kilometres long, have been recognized from exposed shear fabrics occurring south of the Chrome property as well as north and south of the Page property. These are believed to have produced the north-northwest-trending faults and displacements observed on the Chrome and Page properties. The Chrome property has undergone relatively extensive faulting and displacement (up to several metres) compared to the other properties. This is likely the result of its being aligned obliquely to the east-west fault zones. This may have induced more stress on the Chrome property than

Table GS-19-1: Assay results for mineralized gabbro from the Chrome property, Bird River Sill.

Sample	Pd (ppb)	Pt (ppb)	Au (ppb)	Cu (%)	Ni (%)
1	661	170	25	0.041	0.015
2	1.3	4.0	3	0.015	0.006
3	1.6	0.2	-1	-0.001	-0.003
4	0.9	-0.1	-1	-0.001	-0.003
5	1.8	3.8	-1	-0.001	0.003
6	216	122	33	0.097	0.024
7	43.9	31.0	-1	0.003	0.009
8	4.5	4.0	1	0.006	0.018
9	11.9	6.5	6	0.002	0.004
10	13.3	7.0	2	0.002	0.013
11	20.6	18.8	4	0.014	0.013

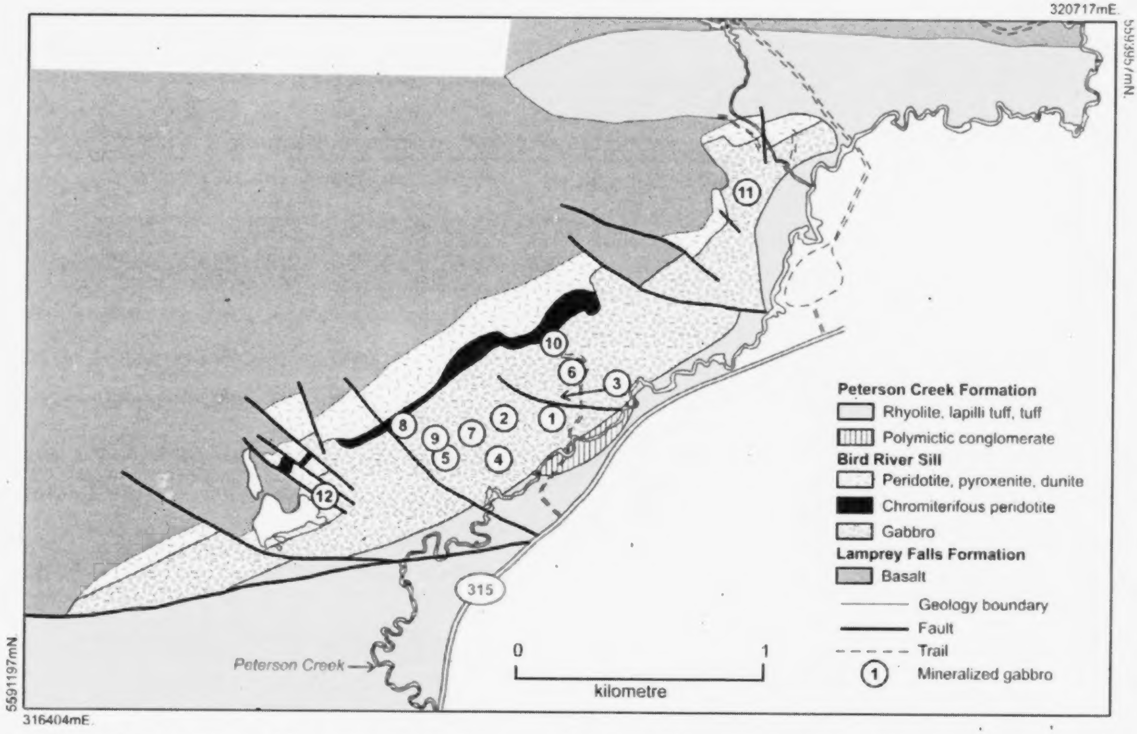
320717mE
5593957mN
5591197mN
316404mE
1
2
3
4
5
6
7
8
9
10
11
12
315
Peterson Creek
0
1
kilometre
Peterson Creek Formation
Rhyolite, lapilli tuff, tuff
Polymictic conglomerate
Bird River Sill
Peridotite, pyroxenite, dunite
Chromiterifous peridotite
Gabbro
Lamprey Falls Formation
Basalt
Geology boundary
Fault
Trail
Mineralized gabbro

Figure GS-19-7: Locations of the mineralized gabbro samples on the Chrome property, Bird River Sill.

on other locations that are parallel to the major structures (i.e., Page property). There is little structural information for the properties west of the Chrome property due to lack of exposure, but the Page and Chrome properties are very well exposed. Further details on the setting of the BRS within the BRGB are provided by Duguet et al. (GS-16, this volume).

Geochemistry

Forty-nine chip samples, 0.5 m in length and collected at 1.5 m intervals from the western channel-sample cut on the Chrome property, were analyzed for whole-rock trace element and sulphur content using inductively coupled plasma mass spectrometry (ICP-MS) and combustion infrared (LECO® carbon-sulphur) analyses, respectively. It is important to note that the sampling section at the current time is incomplete and geochemical analyses of the missing intervals (parts of cycles 1, 3 and 4) are pending.

Preliminary geochemical analysis of the ultramafic rocks indicates a primitive-mantle source. Figure GS-19-8 shows the abundances of immobile trace elements, including rare earth (RE) and high field strength elements. The spider diagram displays a flat pattern which is typical of primitive mantle. Low field strength elements and select transition elements were not included on the spider diagram because they are mobile in greenschist-facies metamorphic conditions. One more important characteristic of the spider diagram is the lack of a negative Nd anomaly. The lack of an Nd anomaly indicates there was no crustal contamination of the Chrome property intrusion.

If the sill was the result of a single magmatic pulse, with subsequent crystal fractionation, it is reasonable to expect that the concentrations of incompatible trace elements such as La and Nd would gradually increase in the residual liquid (i.e. with stratigraphic height; Cawthorn and McCarthy, 1985). By contrast, addition of a new magma can cause increases of trace elements at specific locations (Cawthorn and McCarthy, 1985). Figures GS-19-9a and -9b show an irregular increase of La and Nd stratigraphically upward. The degree of random scatter is inevitable due to variations in the trapped liquid proportion from sample to sample; therefore, to eliminate this effect, a trace element ratio plot is also used (Figure GS-19-9c). The Sm/Nd ratio is fairly constant throughout the ultramafic series. If there had been any magma mixing events or crustal assimilation, there should be either a gradual or an abrupt change in the element ratios. For example, Sm/Yb ratios throughout the stratigraphy of the volcanic pile at the Noril'sk–Talnakh deposit are constant in the lower and middle series but increase abruptly in the upper series, more than doubling in value, indicating mixing of two different magma series (Arndt et al., 2003). A constant ratio throughout the ultramafic rocks of the BRS and gradually increasing trace elements towards the mafic contact both suggest that the sill crystallized from a single magmatic injection.

Conclusions

In summary, it is proposed that the segmented properties of the BRS (i.e., Page, Chrome, Wards) are separate intrusions, possibly fed from the same magma chamber, which were deformed and faulted by late east-trending fault zones, rather than being block-faulted segments of a once-continuous sill. Preliminary geochemical analysis indicates a primitive-mantle source with no evidence of crustal contamination or magma mixing, thus suggesting the Chrome property crystallized from a single magmatic injection. Sulphide and PGE mineralization occur in several horizons in the ultramafic series of the sill but are not solely restricted to the ultramafic portion of the sill, as mineralization has also been identified in the mafic series of the Chrome property, associated with shear zones, likely remobilized, and is known to be present on the Wards property.

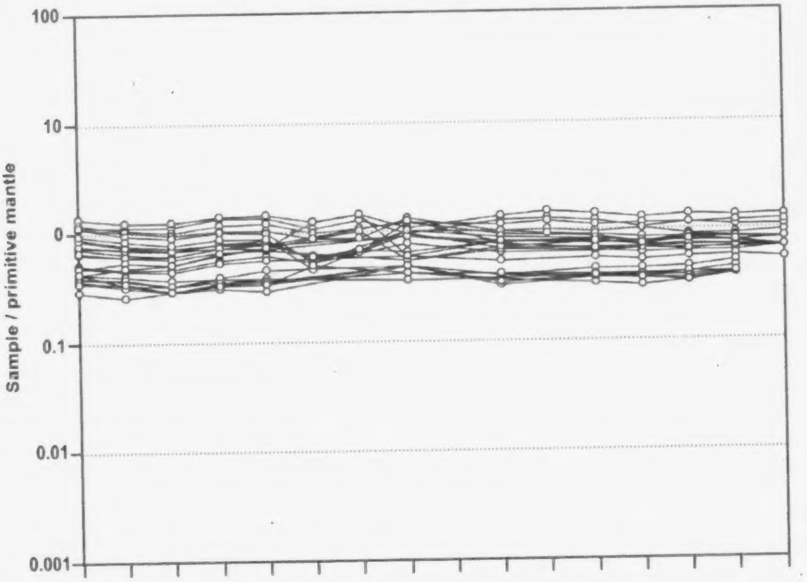

Figure GS-19-8: *Spider diagrams of immobile trace elements and rare earth elements, western channel-sample cut, Chrome property, Bird River Sill.*

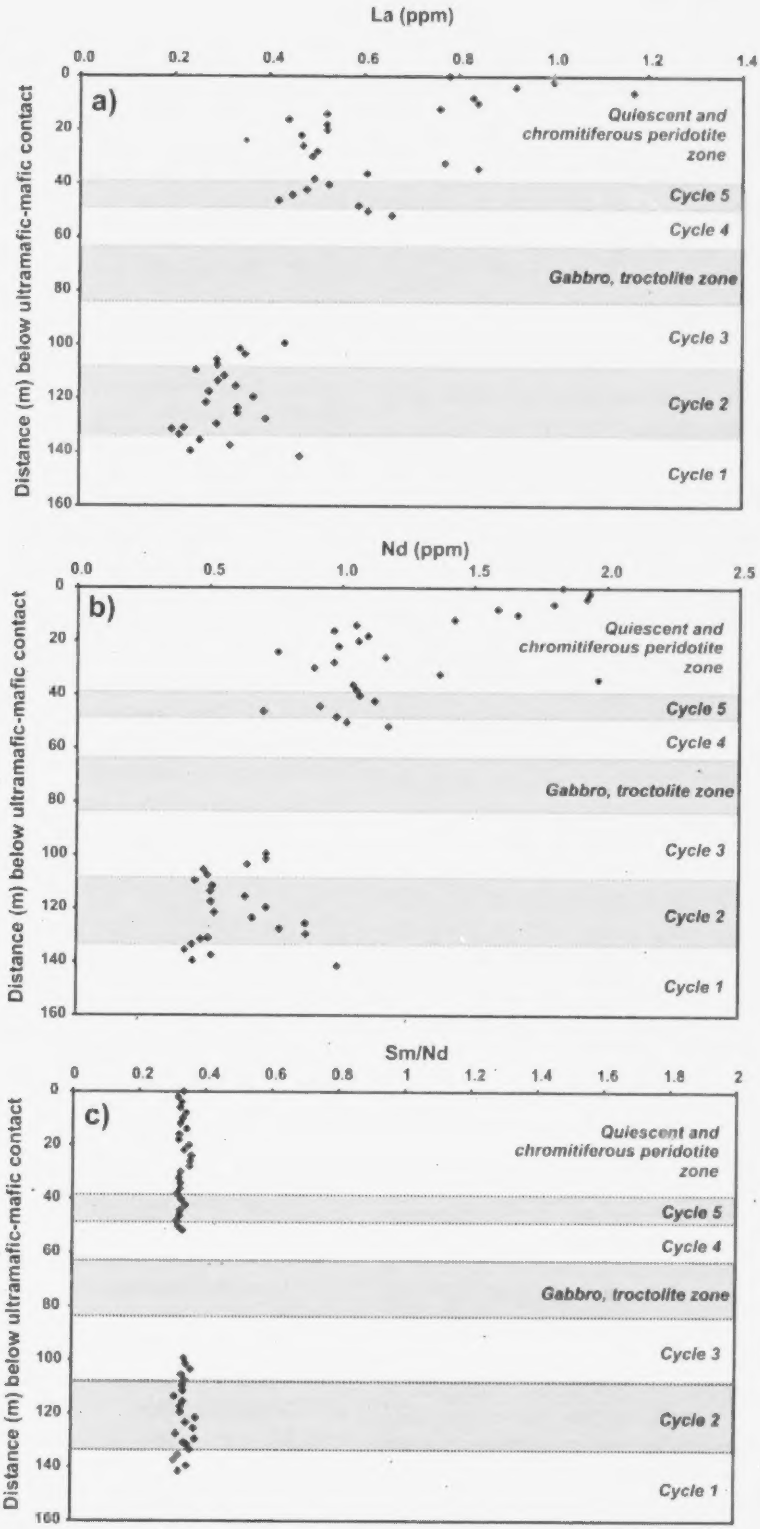

Figure GS-19-9: *Diagrams of incompatible trace elements versus stratigraphy, western channel-sample cut, Chrome property, Bird River Sill.*

Future work

Future work will focus on the following areas:

- Geochemical analysis of the remainder of the western and central channel cuts from the Chrome property and grab samples from the Page property for continued examination of sill petrogenesis
- Petrographic examination of grab samples from the ultramafic and mafic series of the Chrome, Page, Peterson Block and National-Ledin properties to determine the grade of metamorphism and to distinguish alteration from metamorphism
- PGE study emphasizing:
  - PGE mineralogy and habit in the mafic series versus ultramafic series
  - PGE mineralogy and habit in chromitiferous zones versus massive peridotite zones
  - differences and similarities between PGE mineralogy of the separate BRS properties
- Examination of the relationship between the sampled gabbroic intrusions of the Lamprey Falls Formation and the sill
- Sulphur isotope study comparing the Page property, Chrome property, Maskwa-Dumbarton property and sulphide-bearing iron formations local to the Maskwa-Dumbarton property.

Economic considerations

The Bird River Sill (BRS) is an excellent Ni-Cu-PGE exploration target because it 1) hosted two mines on the Maskwa-Dumbarton property, and 2) contains known significant zones of Ni-Cu-PGE mineralization that have not been fully delineated. Within the last two years, drilling by North American Palladium Ltd. has intersected massive sulphide zones containing up to 4 g/t Pd at the base of the sill on the Page property. Sulphide-bearing localities have been identified by this author at the basal contact of the Chrome property and in the gabbro unit on the Chrome property, which was previously believed to be barren but contains up to 861 ppb Pt+Pd, suggesting significant remobilization of the sulphides. The remobilization is also not confined to the limits of the BRS, as sulphides have been identified in the Lamprey Falls Formation, close to the BRS contact and along shear zones and quartz veins.

The relationship between the gabbroic intrusions of the Lamprey Falls Formation and the sill is a very interesting question, especially in light of the Wards property being a gabbroic intrusion into the Lamprey Falls Formation and containing significant PGE and chromite mineralization. The gabbroic intrusions will be a major focus of continued work to delineate any relationship to the known BRS. Further exploration of these intrusions is strongly recommended.

Acknowledgments

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GS-20 Hydrological dynamics in the Winnipeg River basin, Manitoba

by S. St. George[1]

St. George, S. 2006: Hydrological dynamics in the Winnipeg River basin, Manitoba; *in* Report of Activities 2006, Manitoba Science, Technology, Energy and Mines, Manitoba Geological Survey, p. 226-230.

Summary

Because hydrological conditions are the greatest source of risk for hydroelectric production, recent studies describing significant declines in discharge during the 20th century for many Canadian rivers are an understandable cause for concern. The Winnipeg River in northwestern Ontario provides nearly half of the total flow into Lake Winnipeg and the Nelson River, and is the most important component of the hydroelectric system generating power in Manitoba. This study uses a network of long-term discharge gauges to examine the frequency, severity and causes of drought in the basin during the last one hundred years. Extremely low annual flows in the Winnipeg River are the product of widespread reductions in precipitation during the previous summer and autumn, warm temperatures in spring and summer, and very little runoff delivered by spring snowmelt. These conditions are typically associated with circulation similar to the positive mode of the Pacific–North American (PNA) pattern, which may act to inhibit the formation of cyclones in western North America and reduce the amount of precipitation received by northwestern Ontario. A strong, positive PNA-like pattern during autumn and winter appears to be required in order for extreme low flows to occur, but positive PNA anomalies do not always lead to low flows. In contrast to trends observed for other Canadian rivers, annual discharge in the Winnipeg River increased by nearly 60% during the 20th century. Nearly all of this change is due to increases in summer and autumn precipitation and higher discharge during winter. Reports of declining flow for many rivers in the adjacent Canadian Prairies have led to serious concern for the future reliability of water supplies, especially because surface water is the primary source of irrigation for local agriculture. The observed trends toward higher flows suggests that the potential threats to water supply faced by the Canadian Prairie provinces over the next few decades will not include decreasing discharge in the Winnipeg River basin.

Introduction

This study uses a network of long-term discharge gauges to assess how river flow in the Winnipeg River basin (Figure GS-20-1) has behaved during the last one hundred years. Its main goals are to 1) evaluate if river flow increased or decreased during the period of record and investigate the potential causes of such changes; and 2) determine if extreme high or low flows are associated with particular configurations of the synoptic climatology.

Study area and data

Most of the Winnipeg River basin (WRB) is located at the eastern edge of the Canadian Shield in northwestern Ontario, and can be described as a rugged wilderness area with low, rolling terrain and many large lakes. The Winnipeg River, which also drains a small portion of northern Minnesota, flows westward into Manitoba and empties into the south basin of Lake Winnipeg. The basin has an area of approximately 150,000 km^2, and supports more than 100 major lakes (including Lake of the Woods) that occupy more than 11,400 km^2 (Lake of the Woods Control Board, 2002). The basin is largely forested, and serves as a transition zone between the mixed forests of the northern United States and the boreal forest of northern Canada.

Water flow in the WRB has been controlled since the 1880s, when small dams were constructed to aid navigation on Lake of the Woods (Lake of the Woods Control Board, 2002). The first hydroelectric dam in the basin was built on the eastern outlet of Lake of the Woods in 1892, which was followed by a dam on the lake's western outlet in 1925 (Lake of the Woods Control Board, 2002). The Pinawa dam, located on the Winnipeg River, went into operation in 1906 with an initial generating capacity of 8 MW. By 1954, seven additional dams had been built in Manitoba and Ontario, bringing total power production on the river to more than 650 MW. Dams on the Winnipeg River are run-of-river systems, and have limited storage capacity. The only major diversion within the basin transfers water from Lake St. Joseph, which is part of the Albany River basin, into Lac Seul. This channel, built in 1935, adds 80 m^3/s of discharge on average into the Winnipeg River system (Lake of the Woods Control Board, 2002).

Daily and monthly streamflow data were obtained from the Water Survey of Canada's HYDAT data archive (Water Survey of Canada, 2005). Gauges within the Winnipeg River watershed were selected for analysis if they had more than 50 years of record, and were still operating at the end of 2003. Nine gauge records satisfied these criteria, with the longest record (Winnipeg River below Lake of the Woods) beginning in 1892.

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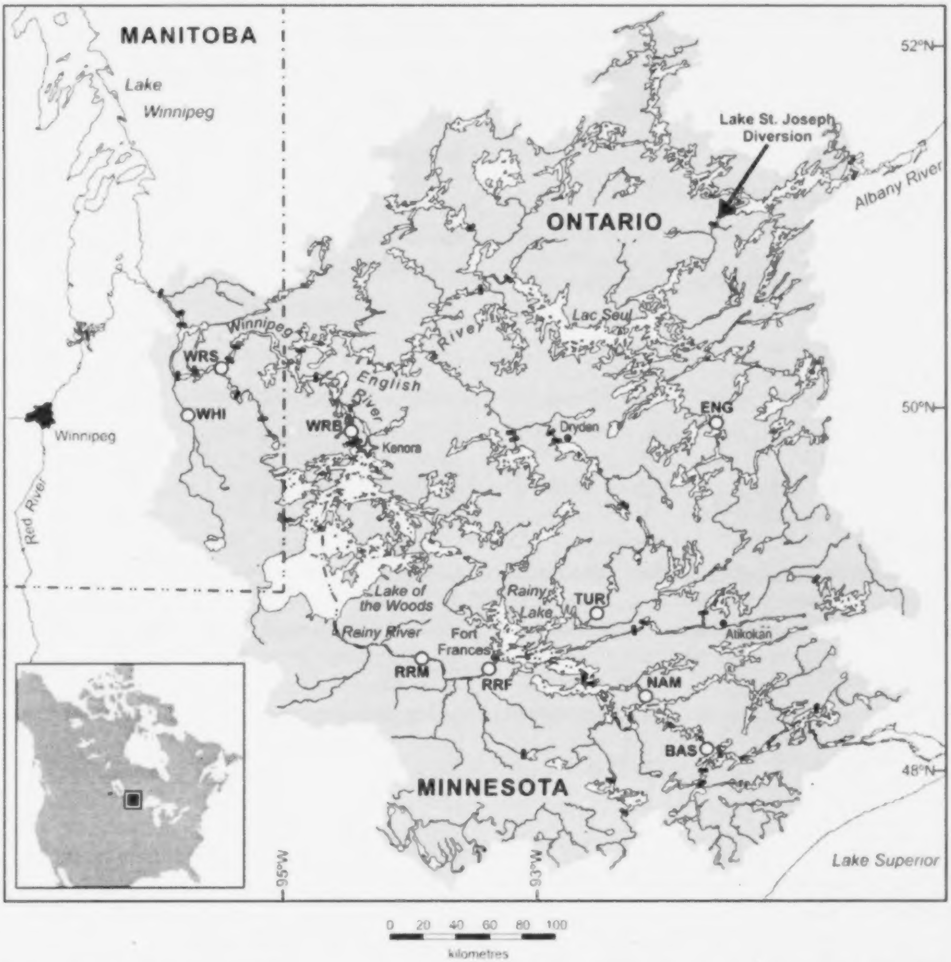
MANITOBA
Lake Winnipeg
ONTARIO
MINNESOTA
Lake St. Joseph Diversion
Albany River
52°N
50°N
48°N
95°W
93°W
Winnipeg River
English River
Lac Seul
Dryden
Kenora
Winnipeg
Red River
Lake of the Woods
Rainy River
Rainy Lake
Fort Frances
Atikokan
Lake Superior
WRS
WHI
WRB
ENG
TUR
RRM
RRF
NAM
BAS
0 20 40 60 80 100
kilometres

WRS	Winnipeg River at Slave Falls	**ENG**	English River at Umfreville	○ Flow gauging stations
WRB	Winnipeg River below Lake of the Woods	**BAS**	Basswood River near Winton	• Communities
RRM	Rainy River at Manitou Rapids	**TUR**	Turtle River near mine centre	▬ Dams
RRF	Rainy River at Fort Frances	**WHI**	Whitemouth River	✧ Climate station
NAM	Namakan River at outlet of Lac La Croix			

Figure GS-20-1: *Map of the Winnipeg River basin showing the locations of the climate station and stream gauges used in this analysis. Base map provided by the Lake of the Woods Control Board.*

Increasing streamflow during the 20th century

Mean annual flows of the Winnipeg River have increased substantially since 1924. At the Slave Falls gauge, annual flows have increased by 4.8 $m^3/s/a$; relative to mean flows at the beginning of the record, this cumulative change corresponds to an increase of 58%. Results for the monthly flow series suggest that the shift to higher annual flows has been driven by large increases in discharge during the winter (Figure GS-20-2). Statistically significant ($p = 0.05$) increases are observed for flows from November to April, ranging between +61 to +110%. There are no significant changes in discharge during the summer months.

The tendency toward higher winter flows is repeated throughout the watershed at gauges upstream from Slave Falls, with seasonal flow increasing by 44 to 128% (not shown). For the Turtle River, significant positive trends in monthly discharge from November to March led to a 46% increase in annual flow. Increasing winter and spring flows were also observed on the Basswood River and the English River at Umfreville, indicating that these seasonal changes occurred over a wide geographic area. However, in the case of the Basswood and English rivers, these seasonal increases were not large enough to cause a significant rise in annual discharge. The trend analysis results also suggest that the English River basin has experienced larger increases in winter flows than have basins in the Lake of the Woods–Rainy River watershed.

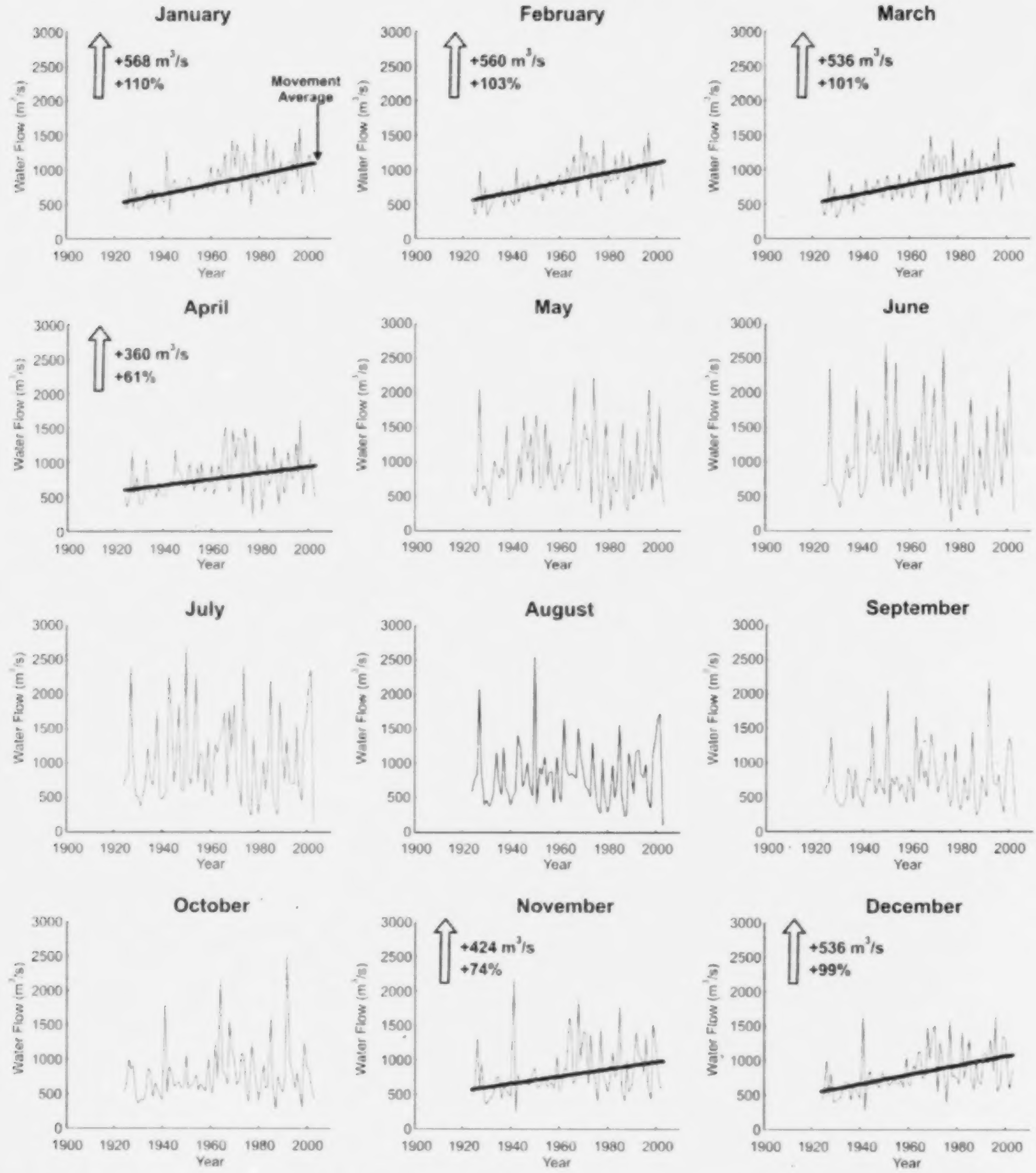

Figure GS-20-2: *Linear trends in monthly streamflow for the Winnipeg River at Slave Falls from 1924 to 2003. Statistically significant increases in flow are highlighted with a heavy line. Total and percent changes are expressed relative to the beginning of the trend line. Discharge is expressed in m³/s.*

Annual and winter discharge also increased on the Big Fork, Sturgeon and Roseau rivers in northern Minnesota after 1960, indicating that trends in the WRB are not artefacts caused by changes in techniques used by Canadian agencies to measure discharge. Although some increases are observed on WRB rivers that are affected by regulation and diversion, the presence of similar trends at upstream gauges demonstrates that direct anthropogenic interference in the hydrological system is not the primary cause of these changes. However, the possibility that some fraction of the trends in flow at the downstream gauges is due to regulation effects cannot be excluded.

Rising winter discharge across the basin has coincided with increasing annual and seasonal precipitation. Total annual (October to September) precipitation at Kenora has increased by approximately 108 mm (15.5%) since 1924. This change largely reflects increases in summer (May to July) and autumn (August to October) precipitation, as no significant trends were observed for winter (November to January) precipitation, and precipitation during spring (February to April) decreased by 25%. No significant trends were identified in annual, monthly or seasonalized temperature records from Kenora. The changes observed at Kenora are part of a general increase in precipitation across much of northwestern Ontario.

Causes of severe low flows

Extremely low flows are typically preceded by widespread reductions in the amount of precipitation received by the WRB in the previous year. Dry conditions become established over northwestern Ontario in summer, and by autumn expand to affect southern Manitoba and northern Minnesota as well. The largest negative precipitation anomalies are centred over the Rainy River basin. Winter snow is also reduced, with most of the basin receiving about 20 mm (~25%) less than average. Spring and summer conditions appear to be less critical to the development of low flows, as mean precipitation anomalies over the basin are close to average during spring and slightly above average in summer. The lowest flows in the smaller, unregulated watersheds (the Basswood, English, Namakan and Turtle rivers) also follow large reductions in precipitation during the previous autumn (not shown), but dry conditions are typically restricted to those individual sub-basins, rather than extending over the entire WRB.

Low-flow years in the WRB are associated with upper-air circulation patterns that cause air masses to move in a north-south trajectory. On average, circulation over western North America is characterized by a 'ridge' of high pressure over the Rockies, and a 'trough' of low pressure that extends over eastern Canada. In the autumn prior to severe drought years in the WRB, the high-pressure ridge over British Columbia becomes strengthened, which forces Pacific air masses to be deflected to the north before moving southeastward across the Prairies. This pattern intensifies through the winter, with the centre of the ridge moving eastward to occupy a position above the northern Rocky Mountains. The ridge's eastward shift is particularly evident prior to the occurrence of low flows in 1977 and 2003. This arrangement of unusual atmospheric conditions is very similar to the positive phase of the Pacific–North American (PNA) pattern (Wallace and Gutzler, 1981). As noted above, precipitation from February to July is not unusually low, but anomalously warm temperatures suggest that increased evaporation during spring and summer acts to reduce runoff and streamflow toward the end of the water-year. Spring and summer temperatures across the basin (not shown) are roughly 2 to 3°C warmer in low-flow years as compared to high-flow years.

Potential connections to the Pacific–North American pattern

As noted, extreme low flows in the Winnipeg River are associated with autumn and winter circulation patterns than resembles the PNA pattern. Many of the lowest flows in the Winnipeg River (1961, 1977, 1981, 1988, 1998 and 2003) followed years when the PNA index was strongly positive (above 0.8). The PNA is also significantly ($p = 0.01$) correlated with annual ($r = -0.36$) and spring ($r = -0.46$) flow at Slave Falls. These results suggest that the state of the PNA may act as an important control on streamflow in the WRB. The index was negative during most of the 1960s and early 1970s, which indicates that this mode may also have contributed to persistently high flows during this period. However, the PNA index was also positive prior to high flows in 1970 and 2001. The geopotential height fields for these two years show the typical PNA pattern over western North America, but also includes regions of anomalous high pressure centred over northern Quebec, the Labrador Sea and southern Greenland. These patterns suggest that the apparent relationship between the PNA and streamflow in the Winnipeg River basin may be modulated by conditions in the North Atlantic sector.

Conclusion

Long-term records indicate that streamflow in the WRB increased significantly during last 80 years, with winter streamflow going up by 44 to 128% at both upstream and downstream gauges over the entire basin. Changes in annual and winter streamflow are observed in records from both regulated and unregulated portions of the watershed, which point to an underlying cause related to climate. Comparisons with long-term meteorological records suggest that the basin hydrology has served to amplify coincident, but smaller, increases in precipitation during summer and autumn.

Extreme low flows in the Winnipeg River are the product of a series of unusual hydroclimatic conditions within the watershed, principally widespread reductions in precipitation during the previous summer and autumn, warm temperatures in spring and summer, and very little runoff delivered by spring snowmelt. These conditions are typically associated with the circulation similar to the positive mode of the PNA pattern, which may act to inhibit the formation of cyclones in western North America and reduce the amount of precipitation received by northwestern Ontario. A strong, positive PNA-like pattern during autumn and winter appears to be required in order for extreme low flows to occur, but positive PNA anomalies do not always lead to low flows. The apparent relationship between streamflow in the WRB and the PNA may be influenced by other competing or complementary factors and these interactions should be investigated in future work.

Reports of declining flow for many rivers in the adjacent Canadian Prairies (Westmacott and Burn, 1997; Yulianti and Burn, 1998; Rood et al., 2005; Déry and Wood, 2005) have led to serious questions about the future reliability of water supplies, especially because surface water is the primary source of irrigation for local agriculture (Gan, 2000). These concerns have been exacerbated by suggestions that a doubling of atmospheric CO_2 could increase the severity and frequency of droughts in the region (Burn, 1994). The results of this study show that the hydrological trends in the WRB during the 20th century are different from those observed on other Canadian rivers, and imply that projections made for the rivers in the Canadian Prairies may not be valid for this watershed. A recent review of results from an ensemble of climate models projects that runoff in the Winnipeg River region and northern and central Manitoba will increase 20 to 30% by the middle of the 21st century (Milly et al., 2005). Because of these projections, and the observed trends toward higher flows, it seems likely that the potential threats to water supply faced by the Canadian Prairie provinces over the next few decades will not include decreasing streamflow in the WRB.

Economic considerations

In Manitoba, hydropower provides nearly 95% of total electricity production (Manitoba Hydro, 2005). Although most of its watershed is in Ontario, the Winnipeg River is the most important component of the hydrological system used to generate power in the province. The river supports six hydroelectric generating stations operated by Manitoba Hydro, which collectively produce 585 MW of electricity (roughly 14% of total provincial production). Furthermore, the river provides nearly half (45%) of the flow into Lake Winnipeg and the Nelson River (despite comprising only 12% of the Nelson River watershed), and has an important influence on the production of nearly 4000 MW at downstream stations on the Nelson River. Widespread drought affecting most of the WRB was cited as the main factor responsible for reducing energy production and sales during the 2003/04 fiscal year (Manitoba Hydro, 2004). Conversely, a return to wetter conditions in 2004 and 2005 was credited with greatly improved hydroelectric conditions in Manitoba (Manitoba Hydro, 2005). Understanding the dynamics of the WRB, including the causes of severe droughts and long-term trends, is critical to developing accurate estimates of future hydroelectric power production in Manitoba.

Acknowledgments

Financial support for this research was provided by Manitoba Hydro, the Manitoba Geological Survey, the Prairie Adaptation Research Collaborative and the Natural Sciences and Engineering Research Council of Canada.

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GS-21 Revegetation of tailings at the Gunnar minesite, Manitoba (NTS 52L14): preliminary observations on plant growth in tailings amended with paper-mill sludge

by S. Renault[1], C. Nakata[1], A. Sabra[1], L. Davis[1] and D. Overton[1]

Renault, S., Nakata, C., Sabra, A., Davis, L. and Overton, D. 2006: Revegetation of tailings at the Gunnar minesite, Manitoba (NTS 52L14): preliminary observations on plant growth in tailings amended with paper-mill sludge; *in* Report of Activities 2006, Manitoba Science, Technology, Energy and Mines, Manitoba Geological Survey, p. 231–233.

Summary

A preliminary field experiment was designed to test the effects of tilling, fertilizing and amending Gunnar tailings with paper-mill sludge on plant establishment and growth. The addition of paper-mill sludge to tailings increased the growth of red fescue and alfalfa. Slender wheatgrass failed to establish in both amended and unamended plots. Although survival was similar, red osier dogwood seedlings planted in sites amended with paper-mill sludge seemed to suffer from less environmental stress than seedlings in unamended sites. These preliminary results suggest that amending the tailings with paper-mill sludge could be beneficial for plant growth in tailings and lays the groundwork for larger scale revegetation studies at the Gunnar minesite.

Introduction

The Gunnar gold mine in Nopiming Provincial Park (lat. 50°51.37′, long. 95°15.31′) was in operation from 1936 to 1942 (Slivitzky, 1996). The tailings are located in a depression south of the mine and cover approximately 11 ha. Acid mine drainage is not a major concern as the pH of the tailings ranges from 6.4 to 8.1 (Slivitzky, 1996; Lambert, 2001; Londry and Sherriff, 2005). In some areas of the tailings, concentrations of copper (160–580 µg/g), arsenic (10–290 µg/g) and cyanide (1.6–20.9 µg/g) exceed the Canadian Interim Remediation Criteria for Soil (CIRCS) agricultural and/or residential/parkland guidelines (Slivitzky, 1996). However, the surface water of the tailings did not contain substantial metals or cyanides.

Half of the tailings have been naturally revegetated showing a typical pattern of succession. Despite the lack of vegetation over the remaining area, some plants are growing along some cracks in the tailings and where organic debris has accumulated (Figure GS-21-1). The lack of vegetation on the tailings may be due to low organic matter content and compaction of the tailings, which limits oxygen and water availability. Previous studies have shown that the amendment of tailings with peat or paper-mill sludge and fertilizer followed by rototilling significantly improved plant growth on Central Manitoba (Au) mine tailings (Renault et al., 2004; Renault and Green, 2005).

Objectives

The objective of the study was to conduct a preliminary experiment to determine the effects of paper-mill sludge and fertilizer on the establishment and growth of

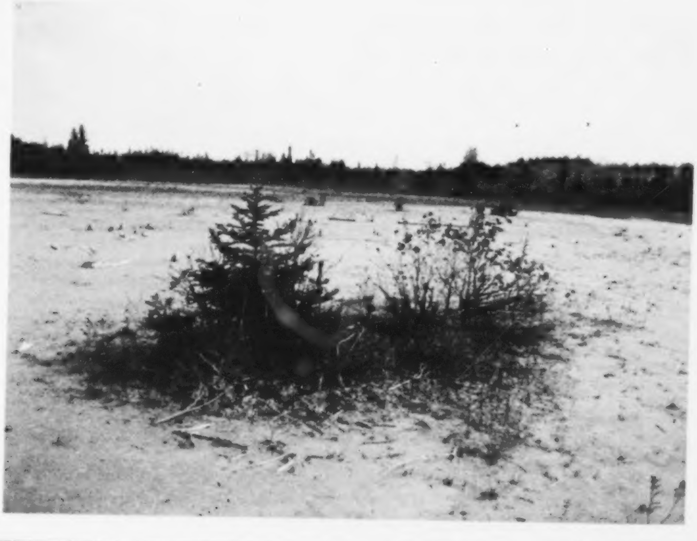

Figure GS-21-1: *Isolated plant growth on Gunnar minesite tailings.*

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two grasses, one legume and a shrub species in Gunnar tailings. The long-term goal is to provide recommendations for the revegetation of mine tailings in Manitoba.

Materials and methods

In May 2006, the locations of the experimental sites were chosen based on homogeneity in colour, topography and vegetation cover of the tailings. Experimental plots were prepared based on a randomized block design with two treatments and four replicates. One subplot from each replicate was randomly chosen and treated with 5.6 kg/m^2 of paper-mill sludge whereas no sludge was added to the control subplot (Figure GS-21-2). All subplots were fertilized with 700 kg/ha of 10-20-10 nitrogen-phosphorus-potassium (NPK) fertilizer plus 125 kg/ha of micronutrients and mixed to a depth of 15 cm with a rototiller. A seed mixture containing 30 kg/ha slender wheatgrass (*Agropyron trachycaulum*), 30 kg/hared fescue (*Festucal rubra*), and 30 kg/ha alfalfa (*Medicago sativa*) was sowed in ¾ of each subplot and red osier dogwood (*Cornus sericea*) seedlings were planted in the remaining portion of each subplot. In September 2006, plant establishment, growth and injury/stress were assessed. Tailings samples were collected in each plot for determination of bulk density and element content.

Results and discussion

The number of plants that grew in each treatment plot is summarized in Table GS-21-1. We recorded only a small number of plants in the control plots (rototilled and fertilized), while the addition of paper-mill sludge greatly improved the growth of red fescue and alfalfa to a lesser extent (Figure GS-21-3). The plants did not show any visible injury or symptoms of deficiency. Slender wheatgrass did not grow on the tailings, with or without paper-mill sludge. The red osier dogwood seedlings in both treatments survived; however, by early July, signs of stress expressed as reddening of leaves and marginal leaf necrosis could be observed. By early September, the only red osier dogwood that was actively growing was in the tailings amended with paper-mill sludge. Leaf abscission had occurred in red osier dogwood plants growing in the sludge-amended tailings whereas dry leaves were still attached to the plants in unamended control plots. This suggests that the leaves of the control plants may have been exposed to a more severe stress (such as drought)

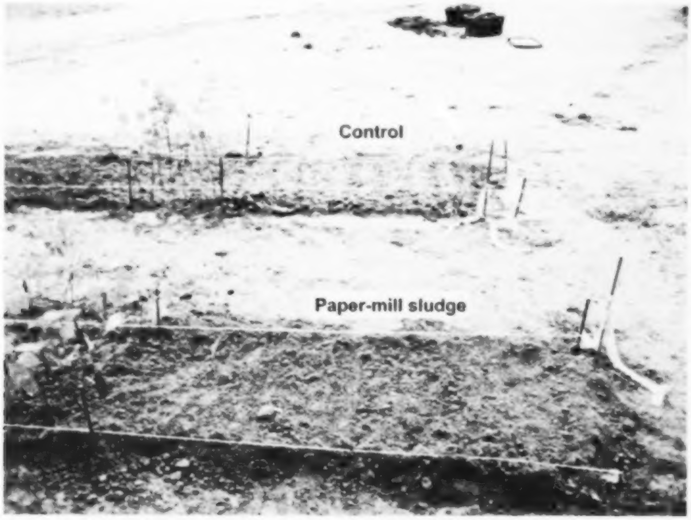

Figure GS-21-2: *Experimental plots at Gunnar minesite.*

Table GS-21-1: Number of plants growing in tailings amended with paper-mill sludge and in control plots at the end of the growing season. The values represent the means, plus or minus the standard error, of four replicates.

Plant/shrub	Sludge-amended plots (no. of plants)	Control plots (no. of plants)
Red fescue	11.75 ±3.20	2.00 ±0.91
Slender wheatgrass	0	0
Alfalfa	3.25 ±1.65	0.25 ±0.25
Red osier dogwood	1 plant actively growing 19 plants without leaves	no plants growing 20 plants with dry leaves

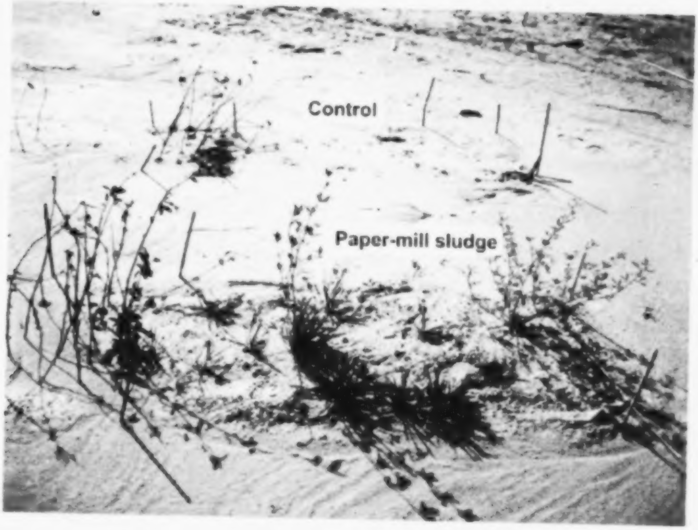

Figure GS-21-3: *Plants growing in unamended control plots and in tailings amended with paper-mill sludge, September 2006.*

than the ones growing in amended tailings.

These preliminary results suggest that the addition of paper-mill sludge to the tailings could improve plant growth by improving water and nutrient availability at least for some of the selected species. Paper-mill sludge has been shown to modify the physical properties of tailings from Central Manitoba minesite in a greenhouse experiment. An increase in organic content, macro-aggregate content, field capacity and a decrease in the bulk density of the tailings was recorded (Green and Renault, unpublished data, 2006). To determine the suitability of paper-mill sludge, a larger scale field study will be undertaken in 2007 at the Gunnar minesite.

Economic considerations

Reclamation of land impacted by the extraction of natural resources is a current challenge for the government and industry. Fundamental revegetation techniques such as seedbed preparation, fertilization and seeding are oftentimes inadequate for successful revegetation of mine tailings (Munshower, 1994). Research oriented towards using readily available amendments, such as paper-mill sludge, to increase revegetation success on such sites would benefit the paper-mill industry, mining industry as well as the government and future land users.

Acknowledgments

This work has been funded by the Manitoba Geological Survey and the Department of Botany, University of Manitoba. Thanks to Tembec Paper Company for supplying the paper-mill sludge and Manitoba Conservation for the work permit (WPB20428).

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GS-22 Aggregate resources in the Rural Municipality of Ste. Rose, Manitoba (NTS 62J13 and 14, 62O3 and 4)

by H.D. Groom

Groom, H.D. 2006: Aggregate resources in the Rural Municipality of Ste. Rose, Manitoba (NTS 62J13 and 14, 62O3 and 4); *in* Report of Activities 2006, Manitoba Science, Technology, Energy and Mines, Manitoba Geological Survey, p. 234–239.

Summary

The Rural Municipality of Ste. Rose was mapped this year as part of an ongoing project to update aggregate information in the province. The last study of this rural municipality was completed in 1978. The aggregate resources are contained in beach ridges formed by glacial Lake Agassiz. There are two major beach complexes: the Ste. Amelie ridge, which has been a long-standing source of aggregate, and a second ridge along the eastern boundary of the municipality which, due to inaccessibility, has only one pit. The material in the complexes ranges from sandy coarse pebble gravel to fine sand. The gravel is of very high quality, with a pebble lithology averaging 75% carbonate and 25% Precambrian clasts and a good range of grain sizes. There is no shale in the aggregate and the only deleterious material was some carbonate cementation.

While many of the pits in the Ste. Amelie ridge are near depletion, it still contains large reserves of aggregate. The eastern deposits will become more important as the Ste. Amelie ridge becomes depleted.

Introduction

An aggregate inventory of the Rural Municipality (R.M.) of Ste. Rose was carried out this summer. The municipality was originally mapped for aggregate in 1978. The information gathered is included in municipal development plans, used for resource management within the MGS and is available to other government departments and outside clients on request.

The R.M. is located in west-central Manitoba, southeast of Dauphin Lake (Figure GS-22-1). The municipality covers approximately six townships, townships 22 to 25 in ranges 14 to 16 W 1st Mer., and is located on NTS sheets 62J13 and 14, 62O3 and 4.

Provincial highways 5 and 68, Provincial roads 276, 360 and 480, and a network of section roads give good access to most of the area. The major village in the municipality is Ste. Rose du Lac but the major service centre is the city of Dauphin, 30 km to the west. The primary industry is mixed farming.

Previous work

There is very little bedrock outcrop in the municipality. However, Bamburak and Christopher present two sections and two borehole logs from the R.M. in their field trip guidebook (Bamburak and Christopher, 2004). References to early work and other regional studies are also found in this guidebook.

The municipality is covered by two reports on groundwater availability: Neepawa area (NTS 62J; Betcher, 1989) and Dauphin Lake (NTS 62O; Betcher, 1987). These reports contain 1:250 000 scale maps of bedrock geology, surficial geology and overburden thickness as well as maps more directly related to water resources.

The surficial geology of the R.M. was mapped at a scale of 1:50 000 by Gartner Lee Associates (1978) as part of an aggregate mapping project that included ten municipalities. The emphasis was on aggregate deposits and much of the mapping of other surface materials was based on soil reports and airphoto interpretation. The area is also included on two recent 1:250 000 scale surficial geology compilation maps: SG-62J (Matile and Keller, 2004a) and SG-62O (Matile and Keller, 2004b). On these maps, the surface units have been draped over topographic relief maps and landforms, many that are ice-flow directional indicators, are very clearly shown.

Geology

Bedrock geology

The R.M. of Ste. Rose is underlain by Mesozoic and Paleozoic rocks (Figure GS-22-2). The majority of the municipality is underlain by Cretaceous and Jurassic sedimentary rocks while Devonian carbonate strata underlie the northern and eastern edges of the area. There is very little outcrop in the area and the bedrock information here has been taken primarily from Bamburak and Christopher (2004), who compiled existing information for their field trip guidebook.

The Cretaceous Swan River Formation is formed primarily of sandstone with minor shale beds. However, in the R.M. of Ste. Rose only the shale beds are exposed in quarries and coreholes. The shale is plastic and fairly soft and was used in brick manufacturing. There are two quarries, a large one in NE¼, Sec. 4, Twp. 23, Rge. 15, W 1st Mer. (NE-4-23-15-W1) and a much smaller one in SE-4-23-15-W1 (Figure GS-22-2). Both are inactive and flooded thus strata are not currently exposed. Both quarries have old stockpiles from which material is occasionally removed. The Swan River Formation strata

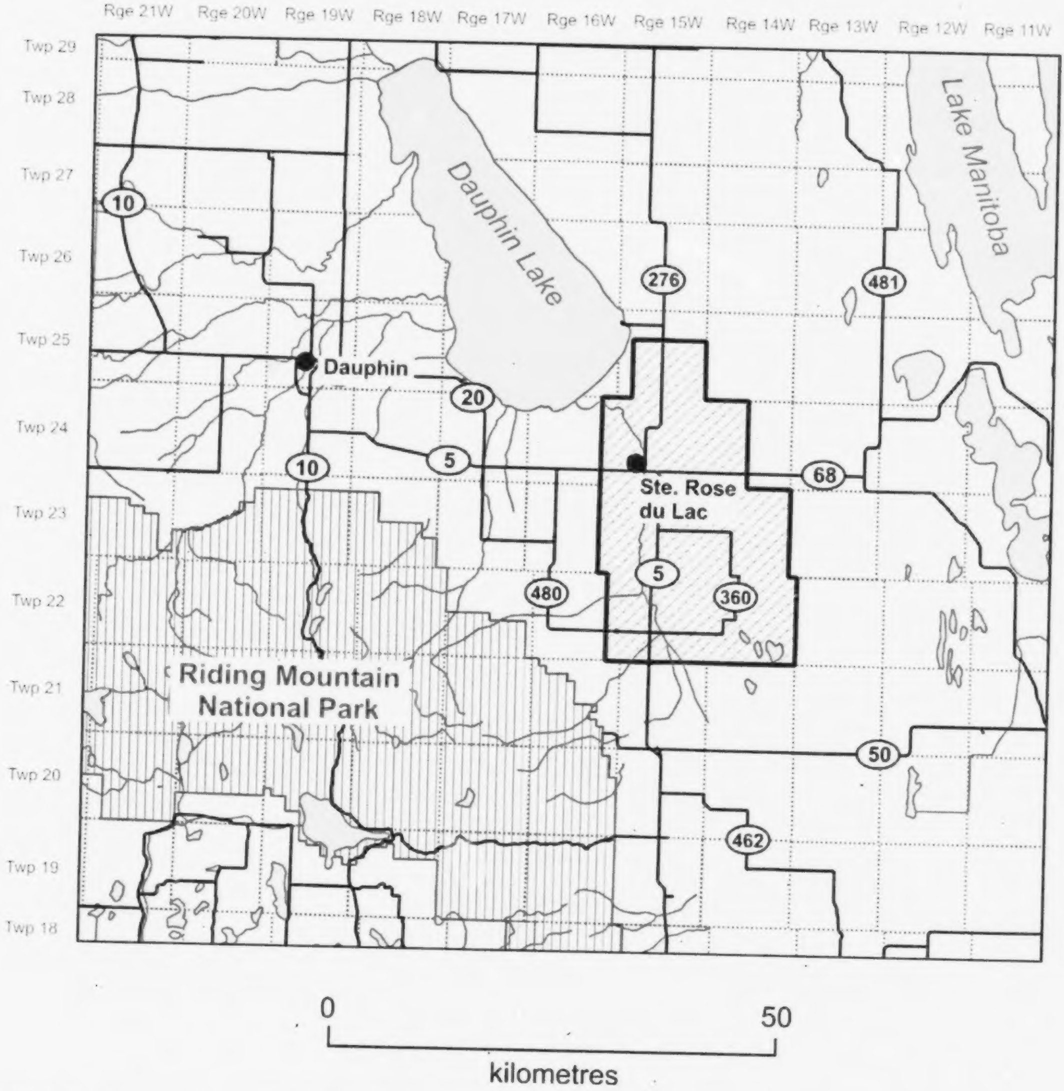
Rge 21W
Rge 20W
Rge 19W
Rge 18W
Rge 17W
Rge 16W
Rge 15W
Rge 14W
Rge 13W
Rge 12W
Rge 11W
Twp 29
Twp 28
Twp 27
Twp 26
Twp 25
Twp 24
Twp 23
Twp 22
Twp 21
Twp 20
Twp 19
Twp 18
Dauphin Lake
Lake Manitoba
10
276
481
Dauphin
20
5
10
68
Ste. Rose du Lac
5
480
360
Riding Mountain National Park
50
462
0
50
kilometres

Figure GS-22-1: *Location map of the R.M. of Ste. Rose.*

are described in Stop 19 in Bamburak and Christopher (2004). There is some discrepancy in the identification of the beds of the Swan River Formation. M. Shayna's quarry description ascribed the lower kaolinitic shale and the red clay bed to the Jurassic Melita Formation (Shayna, 1975). H.R. McCabe's corehole description ascribed all the beds to the Swan River Formation (McCabe, unpublished data, 1978). J. Bamburak (pers comm, 2006) includes the kaolinitic shale within the Swan River Formation beds but considers the red clay bed to be the top of the Melita Formation.

The Jurassic Melita Formation is composed of shale and calcareous sandstone. It is encountered in coreholes and exposed in the two quarries in the municipality, as described above.

The Jurassic Reston Formation is composed of interbedded calcareous shale and limestone. It is seen in outcrop in a riverbank exposure (4-24-15-W1) and encountered in one corehole in 22-23-15-W1. The Reston Formation section and corehole are described in Stop 18 in Bamburak and Christopher (2004).

The Devonian Souris River Formation consists primarily of limestone and dolomite. Overburden thicknesses range from 20 to 40 m in this area (Betcher, 1987) and the Devonian strata were not seen in outcrop in the municipality.

Surficial geology and glacial history

Overburden thicknesses range from 4 m, where the

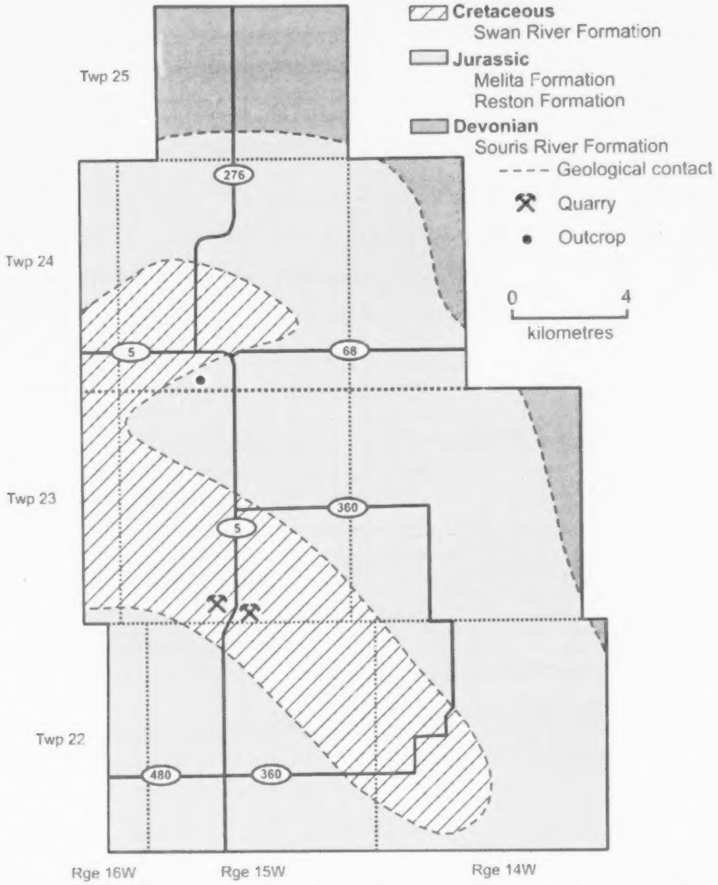

*Figure GS-22-2: Bedrock geology of the R.M. of Ste. Rose, showing quarry and outcrop locations (*modified from *Betcher, 1987, 1989; Bannatyne, 1971).*

quarries are located (4-23-15-W1), to 40 m in the west (Betcher, 1987, 1989). The surficial sediments in the municipality comprise glacial till, glaciolacustrine gravel, sand, silt and clay and modern organics (Figure GS-22-3).

Glacial till is by far the most extensive unit. The till is brownish yellow, silty and calcareous. The pebble fraction contains a high percentage of angular carbonate clasts. Klassen (1979) mapped the area immediately west of the R.M. of Ste. Rose, NTS map sheet 62N, and identified this till as the Arran Formation. The Arran till in the R.M. of Ste. Rose contains 34 to 65% carbonate and is from 2 to 5 m thick.

Glaciolacustrine sand, silt and clay cover most of the northern and western parts of the municipality. Boreholes in the northern part of the R.M. indicate 30 m of till in SW-16-24-14-W1, 1.5 m of sand overlying till in SE-16-24-15-W1 and 5.5 m of clay overlying till in SE-13-24-16-W1 (Betcher, 1987).

Glaciolacustrine sand and gravel is found in beach ridges scattered across the municipality. They are generally oriented in a southeast direction and vary in size from small ridges, 1 to 2 m high, to very large complexes of ridges that are 10 m in height and 1.5 km in width. One large complex runs for approximately 22 km diagonally through the centre of the R.M., starting near the town of Ste. Rose du Lac. It is informally known as the Ste. Amelie ridge. There is a second large complex along the eastern edge of the R.M. Most of this complex is in the adjacent municipality, but part of it runs along the eastern side of 22-14-W1. Smaller beach ridges are situated in the southwest corner of the R.M.

Organic deposits are found in low-lying areas particularly in the southeastern part of the municipality where the eastern beach complex blocks the natural, gentle northeast drainage pattern. The deposits are too small to be shown on Figure GS-22-3.

These surface deposits, except for the modern organics, were formed by glacial processes. The last glacial advance came from the northeast, over carbonate rocks, depositing the calcareous Arran till. During deglaciation, glacial Lake Agassiz inundated the area, ponding between

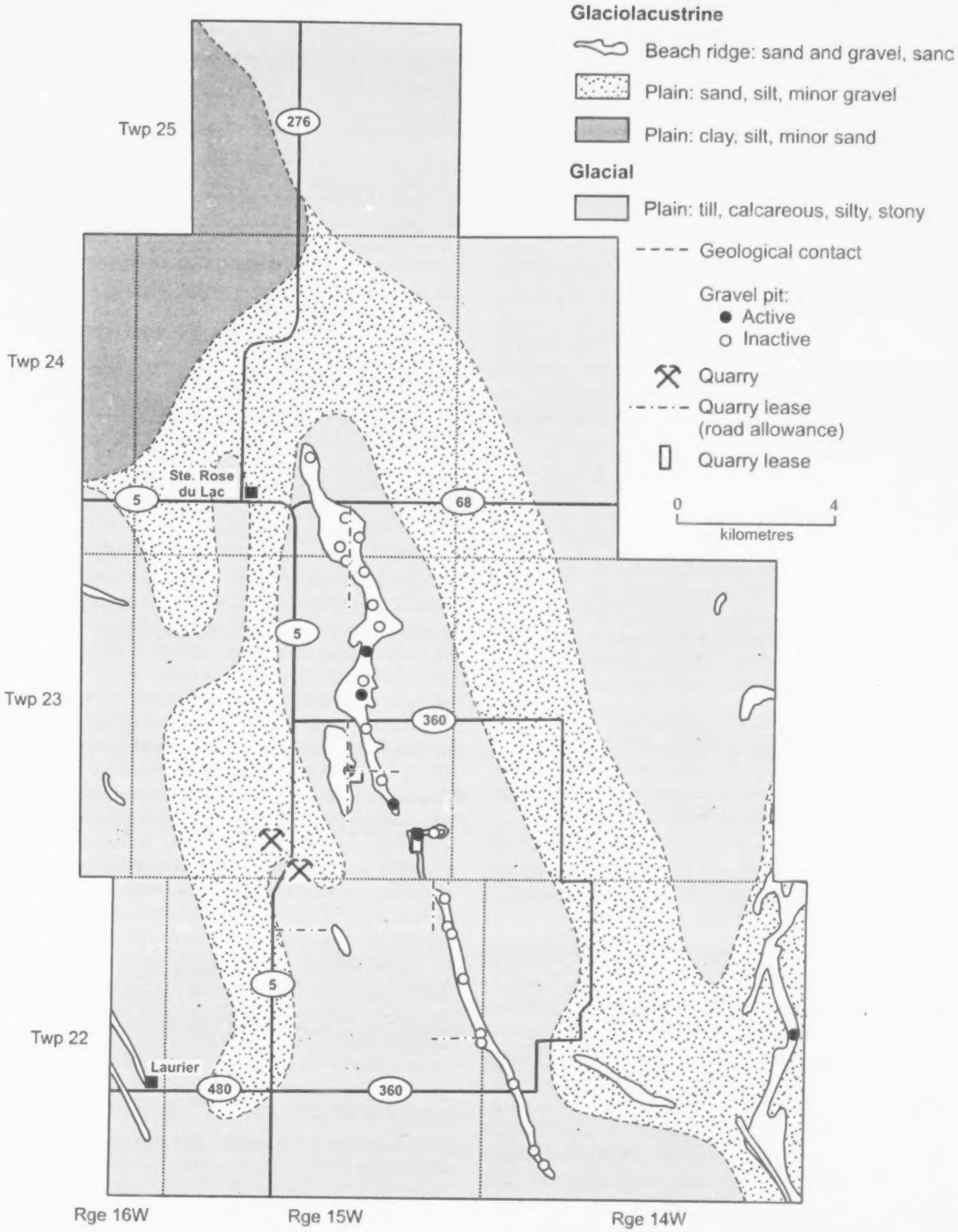
Glaciolacustrine
Beach ridge: sand and gravel, sanc
Plain: sand, silt, minor gravel
Plain: clay, silt, minor sand
Glacial
Plain: till, calcareous, silty, stony
Geological contact
Gravel pit:
Active
Inactive
Quarry
Quarry lease
(road allowance)
Quarry lease
0
4
kilometres
Twp 25
Twp 24
Twp 23
Twp 22
276
5
68
360
480
Ste. Rose
du Lac
Laurier
Rge 16W
Rge 15W
Rge 14W

Figure GS-22-3: *Map of the R.M. of Ste. Rose, showing gravel deposits, pit and quarry locations and surficial deposits (modified from Matile and Keller, 2004a, b).*

the retreating ice to the east and the height of land to the west. Beach ridges formed discontinuously along the edge of the lake. As the ice retreated, the lake also retreated, with the resulting formation of beaches at successively lower elevations. Working in Manitoba and the adjacent parts of Saskatchewan and Ontario, Johnston (1946) took beach elevations around the former lake and, taking into account differential uplift, recreated shorelines at the various lake levels. The two beach complexes in the R.M. of Ste. Rose record the Gladstone level at 290 m above sea level (asl), the Burnside at 282 m asl and the Ossawa at 272 m asl. The majority of the gravel pits in the Ste. Amelie ridge are about 2 m deep and, from a limited number of exposures, the gravel appears to be underlain by till. Given that the ridge is 10 m high, it is possible that the bulk of the ridge formed either subglacially or at the ice margin before glacial Lake Agassiz entered the area. Once glacial Lake Agassiz formed, the beach deposits formed on the ridge.

Aggregate inventory

Methodology

The aggregate inventory was carried out in two stages: office compilation followed by fieldwork. Previously mapped deposits were transferred onto 1:20 000 township photomosaics and 1:10 000 section photos (1996 orthophotos). The township mosaics were used as a base on which to compile aggregate information from several sources:

1) active pit and quarry locations – Mines Branch quarry database;
2) lease and withdrawn locations – Mines Branch plat books and digital shape files;
3) Crown versus private ownership – Manitoba Crown Lands Branch database;
4) pit and sample locations – Geological Survey Pleistocene database;
5) pit and sample locations – Department of Highways block files; and
6) mineral inventory cards – Manitoba Geological Survey.

Quarries, gravel pits, road cuts and natural exposures were examined during the first part of the field examination. Pits and quarries were examined for type of material, degree of depletion and active/inactive/depleted status. Unopened portions of deposits were inspected and land uses that would limit aggregate extraction noted. Site locations were taken by GPS using UTM co-ordinates, as well as by section-township-range notation. In addition, the GPS co-ordinates of bedrock outcrops were also recorded.

Aggregate resources

The aggregate resources of the municipality are all found in sand and gravel beach ridges. Bedrock strata found in the quarries are too soft to be used as aggregate. Gravel ownership is mainly private but there is some crown-owned gravel. Most of the quarry leases are along road allowances, but the lease in NW-1-23-15-W1 is currently the most active extraction area. Figure GS-22-3 shows the location of gravel deposits, pits and quarries.

The Ste. Amelie ridge runs, in discontinuous segments, southeast through the centre of the municipality for over 22 km. The ridge has long been the major source of aggregate for the area. Many of the pits existing today were active when Gartner Lee Associates (1978) did their study. The pits range from 1 to 3 m in depth and till is occasionally exposed at the pit base. The material ranges from sandy coarse pebble gravel to fine sand. The gravel is of very high quality, with a pebble lithology averaging 75% carbonate and 25% Precambrian clasts and a good range of grain sizes. There is no shale in the aggregate and the only deleterious material was some carbonate cementation.

The northern segment of the ridge is virtually one long pit. In some of the older pits, minor amounts of material are being removed, such as in NW-10-24-15-W1. Others have been reactivated such as SW-26-23-15-W1 where there is 1.5 m sandy pebble gravel in the active area. The old part of the pit in NW-26-23-15-W1 is the site of several small stockpiles of screened material. In 23-23-15-W1, the large pit in the northwest contains crown gravel, which had been extensively removed until 2001; in the southwest, the gravel is owned by the municipality and last removed in 2004. In the east half of 11-23-15-W1, the old pit area runs the entire 1.6 km length of Section 11. There has been some limited removal recently with small stockpiles of screened material on site. The municipality holds the leases in the NW-11-23-15-W1 and there has been limited removal recently from the old pit there.

There are two pits in the middle segment of the ridge, 1-23-15-W1. The inactive pit in the northeast quarter is ~3 m deep and primarily sand remains. The active pit in the northwest is operated under a quarry lease. The pit reveals 2 m of high quality sandy pebble gravel with a good amount of crushable clasts. The pit is extensive, rather than deep.

The southern segment of the ridge consists of 1 to 2 m of sandy pebble gravel. It has been extensively mined in the past. Some pits have minor amounts of aggregate being removed, but there are no commercially active pits at present.

The sand and gravel ridges along the east side of 22-14-W1 were backhoe tested by Gartner Lee Associates (1978). There were four sites and the aggregate ranged from 2 m to >6 m of interbedded sandy pebble gravel, pebbly sand and sand. There is one pit (SE-24-22-14-W1) in the deposit from which the municipality removed aggregate in 2003 and has obtained permits to remove more material. The ridges trend northeast out of the municipality, into 23-13-W1. The ridges outside the municipality were backhoe tested in 1998 as part of a study of the Alonsa Wildlife Management Area (H. Groom, unpublished data, 1998). Twenty-one sites were excavated by backhoe. Most of the test pits were ~3 m deep and all pits ended in granular material. The material ranged from beds of cobbly coarse gravel to very good quality sandy pebble gravel to pebbly sand and sand. The gravel was predominantly composed of carbonate clasts and cementation was the only deleterious element.

The small beach ridges near Laurier contain 1 to 1.5 m of pebbly sand and fine pebble gravel. Material has been extracted from them in the past but they are not currently active. The remaining beach ridges are small and predominantly sand. There are also several small ridges of silty, sandy material that were probably formed as offshore bars. They have no economic value, except perhaps as fill.

Economic considerations

Aggregate is a high-bulk, low-value commodity so the haulage cost is often an important factor in the final cost of aggregate for a project. In general, the value of aggregate reserves in any specific area depends on the abundance of the resources and on the demand. Due to the haulage factor, the fewer the resources or the greater the demand, the more important it is to protect those resources from activities, such as building construction, that would prevent them being utilized. The R.M. of Ste. Rose has been very fortunate to have an abundance of high quality aggregate in the beach ridges of the area. While there is still considerable aggregate remaining in the Ste. Amelie ridge, many of the pits have been depleted of the best quality material. As depletion continues, the beach ridges along the east side of 22-14-W1 will be an important source of sand and gravel.

Acknowledgments

J. Bamburak is thanked for providing information on the bedrock strata.

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GS-23 Summary of investigations for the Sedimentary and Industrial Minerals Section, Manitoba Geological Survey

by R.K. Bezys

Bezys, R.K. 2006: Summary of investigations for the Sedimentary and Industrial Minerals Section, Manitoba Geological Survey; *in* Report of Activities 2006, Manitoba Science, Technology, Energy and Mines, Manitoba Geological Survey, p. 240–245.

Summary

The Sedimentary and Industrial Minerals Section of the Manitoba Geological Survey engaged in limited fieldwork in 2006, although numerous office-based projects continued or were initiated. Some projects, such as the Williston Basin TGI (Targeted Geoscience Initiative) project, had some minor achievements, while others, such as the surficial geology compilation of Manitoba and the Phanerozoic lineament study, have made great progress. This year's summary will include an update on stratigraphic corehole drilling carried out late last summer (2005). Staff has also been responsible for responding to numerous requests for information on industrial minerals and aggregate deposits, as well as leading field trips. Support was also provided for the new mineral deposit database and the St-Lazare potash study.

Introduction

The main focus of study for projects in the Sedimentary and Industrial Minerals Section included

- Phanerozoic lineament study;
- surficial geology compilation of Manitoba;
- Williston Basin TGI project;
- stratigraphic corehole drilling, 2005; and
- miscellaneous studies.

Limited progress was made on the Williston Basin TGI project, but progress was made on the Phanerozoic lineament study, which is a co-operative study between the Manitoba Geological Survey, Saskatchewan Industry Resources and the Alberta Geological Survey. Significant progress has been made on the surficial geology compilation of Manitoba. Thirty-seven 1:250 000 scale maps, four 1:500 000 scale maps and a prototype of the 1:1 000 000 scale map are to be released this year. Two coreholes were drilled in 2005 for the Manitoba Stratigraphic Database, both in the Grand Rapids area and a further two holes were drilled in west-central Manitoba in 2006 to assist in the understanding of Devonian stratigraphy (Bamburak, GS-24, this volume). The section is also assisting with the compilation of the mineral deposit database, which will be based on the MGS Mineral Deposit Series, with additional information from recently opened, cancelled assessment files (Heine, GS-26, this volume). Aggregate studies were conducted in the Rural Municipality of Ste. Rose as part of an ongoing project to update aggregate information in the province (Groom, GS-22, this volume). Also, GIS assistance is being provided to the Mines Branch for the digitization of all land and mineral rights, along with surface ownership, for the St-Lazare potash project area.

Phanerozoic lineament study

As indicated in Bezys (2005), a start has been made on the Phanerozoic lineament study, the compilation of a database of Phanerozoic structural information for the Western Canada Sedimentary Basin (WCSB) by the Alberta, Saskatchewan and Manitoba geological surveys. The joint prototype structural database has been designed to document structures that may have localized hydrocarbon and metal-bearing fluids in traps within the Phanerozoic stratigraphic package. A two-pronged approach to collecting the lineament data is being taken in Manitoba. The first objective is to compile an inventory of published maps and figures of lineaments. This is followed by digitizing the lineaments into ArcView® layers (i.e., shapefiles) and individually tagging them with attribute data. The second objective is to obtain GIS digital shapefiles from published sources, such as Manitoba's Integrated Anomaly Map (Manitoba Geological Survey, 2006; Figure GS-23-1) and the printed NATMAP Shield Margin Project Area map (NATMAP Shield Margin Project Working Group, 1998). The respective attribute tables from these sources are then modified to fit the format of the joint provincial database. Additional details of the project are discussed by Pana et al. (in press) in an extended abstract released at the Saskatchewan and Northern Plains Oil and Gas Symposium in Regina, Saskatchewan (October, 2006).

Surficial geology compilation of Manitoba

A significant portion of the surficial maps of Manitoba are now available in a digital form. Last year, sixteen 1:250 000 scale and one 1:500 000 scale maps of southern Manitoba were released in digital form and this year, thirty-seven 1:250 000 scale maps, four 1:500 000 scale maps and a prototype of the 1:1 000 000 scale map are available, covering the remainder of the province. The original paper maps were published in 1981 and had become outdated. The present maps will be in digital and queriable formats and will be an important tool for mineral exploration in Manitoba, as well as for land-use planning.

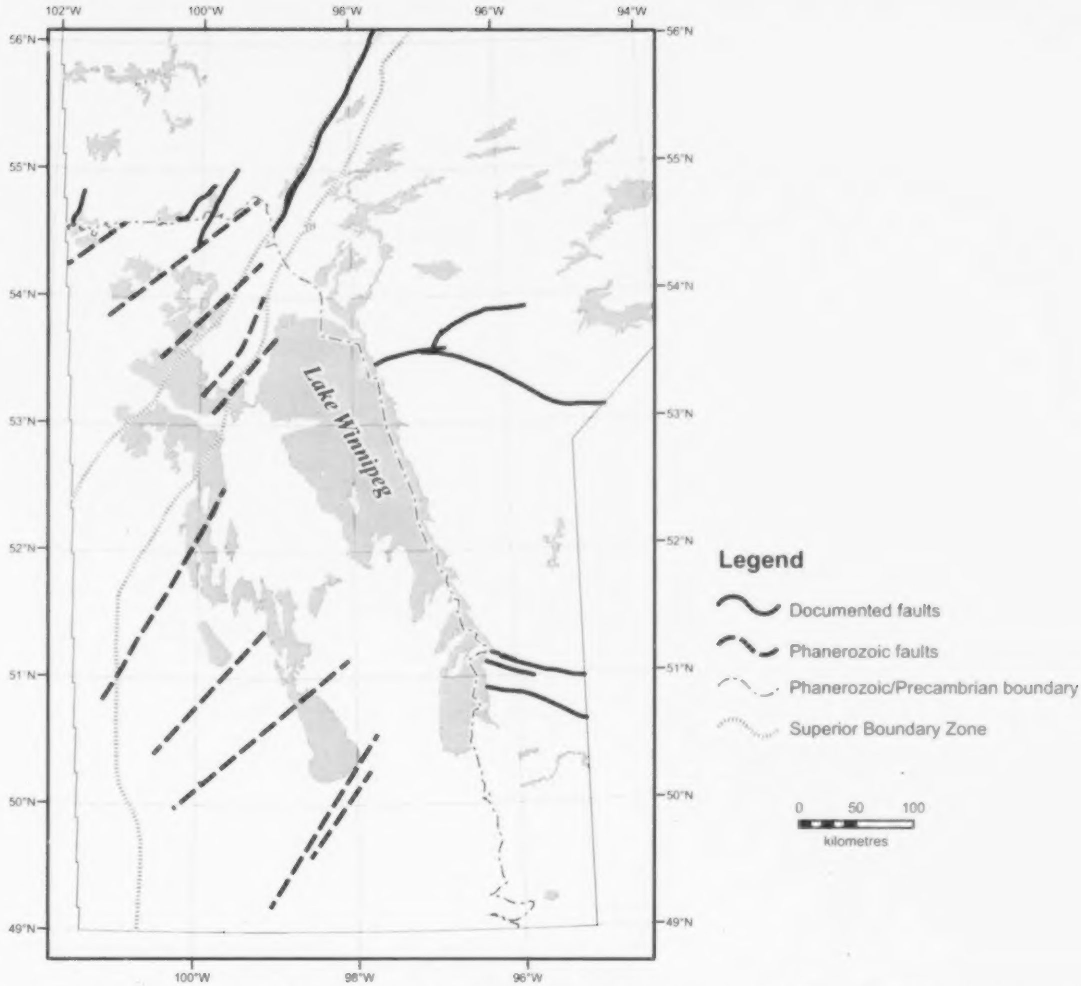

***Figure GS-23-1:** Location of fault lineaments in southwestern Manitoba (Precambrian and Phanerozoic) from Manitoba's Integrated Anomaly Map (Manitoba Geological Survey, 2006).*

Williston Basin TGI project

Interprovincial subsurface stratigraphic correlations for the entire Phanerozoic section have been completed, which has been a significant accomplishment. This was most invaluable for the Mesozoic section, where correlations had not been done to any major extent or with much success. A better understanding of the geological setting and erosional events that affected the Cretaceous shale units in the provinces has resulted in the renaming of a portion of Manitoba's stratigraphic column. This work is significant for shallow gas exploration in the province.

Cross-border correlations of the Bakken Formation, Three Forks Group coincided with the discovery of the Sinclair field, which is being explored for conventional oil. Co-operative maps of and discussions between Manitoba and Saskatchewan have helped in the understanding of the dynamics of this new play, which in turn has helped industry. The compilation of all oil and gas shows throughout the Phanerozoic section has been a useful exploration tool for the industry, especially the compilation of Mesozoic oil and gas shows, which did not exist prior to the start of this project. A detailed and accurate basin-wide model of the geohydrological dynamics of the Williston Basin system has been constructed and will be a valuable tool to study oil–water migration pathways through the Phanerozoic section (particularly the Paleozoic section).

Final map production for the project is to be completed by fiscal year-end (March 2007).

Stratigraphic corehole drilling, 2005

Late in the summer of 2005, two coreholes were drilled in the Grand Rapids area for stratigraphic purposes (Table GS-23-1). Corehole M-1-05 was drilled through

Table GS-23-1: Summary of stratigraphic corehole data, 2005.

Hole No.	Location and elevation (m asl)	SYSTEM/Formation/(Member)	Interval (m)	Lithology summary
M-1-05	02-06-51-14W	SILURIAN INTERLAKE GROUP/ Atikameg	0.0–3.4	Buff yellow dolowackestone, very fine grained, 20% porosity
Ochre Lake	5913325N	U_2-Marker	3.4–5.3	Grey dolomudstone
	466311E	Moose Lake	5.3–17.0	Grey-brown dolomudstone, laminated to massive
	265.2	U_1-Marker	17.0–17.4	Grey-brown dolomudstone, laminated, no sand
		Fisher Branch	17.4–29.8	Light brown to tan dolowackestone to packstone, *Virgiana decussata* at 29.3 m (20 cm bed)
		Stonewall	29.8–51.6	
		Stonewall/(Upper Stonewall Marker)	29.8–30.7	Light grey-beige dolomudstone
		Upper Stonewall	29.8–42.8	Tan dolowackestone
		Upper T-Marker	42.8–43.5	Grey dolomudstone, mottled, sand/shaly in places
		ORDOVICIAN/Lower Stonewall	43.5–51.6	Grey to brown dolomudstone and wackestone, Lower T-Marker not identified
		(Williams)	48.9–51.6	Grey dolomudstone
		Stony Mountain	51.6–85.7	Mottled brown dolowackestone
		Red River	85.7–145.9	
		Upper Red River (Fort Garry)	85.7-97.4	Interbedded massive dolomite, beige to brown to grey mottled, gradational upper contact
		Lower Red River	97.4–145.5	Beige dolowackestone, mottled, gradational upper contact
		(Hecla Beds)	145.5–145.9	Mottled sandy dolomite, pyritic mottling with possible brachiopod molds (1–2 cm across)
		Winnipeg	145.9–154.7	Green shale/siltstone between 145.9–148.5 m, bioturbated in places, fine- to medium-grained sand between 148.5–154.7 m, white to light beige, consolidated, quartzose
		Weathered PRECAMBRIAN	154.7–158.7	Pale green to white, severely kaolinized, friable, unconsolidated, lithology unrecognizable
		PRECAMBRIAN	158.7–161.9	Light grey, fine- to medium-grained, massive, homogenous, nonmagnetic tonalite
M-2-05	14-16-58-12W	ORDOVICIAN/Lower Stonewall	0.0–12.3	Very broken and rubbly core, tan dolowackestone
William Tower	5985262N	Lower T-Marker	3.1–4.6	Grey to brown dolomudstone
	488007E	(Williams)	9.0–12.3	Grey dolomudstone
	281.9	Stony Mountain	12.3–40.8	Mottled tan dolowackestone
		Red River	40.8–84.4	
		Upper Red River (Fort Garry)	40.8–51.0	Mainly grey, mottled, dolomudstone
		Lower Red River	51.0–83.2	Tan dolowackestone
		(Hecla Beds)	83.2–84.4	Very sandy dolomite, mottled, pyritized
		Winnipeg	84.4–90.6	Dark mottled brown sandstone, no shale

the Silurian Interlake Group to the Precambrian, for a depth of 161.9 m. Corehole M-2-05 was drilled through Ordovician strata, starting with the Stonewall Formation, but was terminated above the Precambrian in the Ordovician Winnipeg Formation at a depth of 90.6 m. To view this year's drilling results see Bamburak (GS-24, this volume).

Corehole M-1-05 was drilled at Ochre Lake and corehole M-2-05 was drilled at William Tower (near William Lake) (Figure GS-23-2). The Ochre Lake corehole, M-1-05, was drilled to follow up the anomalous occurrence of disturbed Silurian outcrop that was first reported in 1996 by Bezys (1996a). The area of disturbance follows an outcrop ridge that appears to be lineament controlled, trending 15°. The Reedy Lake Lineament (Bezys, 1996b), 33 km to the north of Ochre Lake, trends in a similar direction (18–20°), which is parallel to the basement trend of the Superior Boundary Zone. Corehole M-1-05 was sited near to the trend of the Ochre Lake lineament to target the Precambrian and determine if the basement rock was disturbed in anyway. The drilling intersected normal Silurian and Ordovician dolomites, with no disturbances found within the Precambrian.

The second corehole, M-2-05, was drilled at William Tower alongside Provincial Highway 6. This corehole was drilled to provide stratigraphic control for The Manitoba Museum staff who is investigating unique paleontological assemblages in the Stonewall Formation (Williams Member) found in nearby outcrop. Work is still progressing on this project and detailed core logging will be conducted.

Miscellaneous studies

Numerous other studies and projects are carried out by the section and are detailed below.

Mineral deposit database

The section is assisting with the compilation of the mineral deposit database, which will be based on the MGS Mineral Deposit Series. Additional information is being provided from recently opened, cancelled assessment files. To date, the section has provided information from over 700 assessment files, including company name, year of work, type of work done and UTM location (Heine, GS-26, this volume).

Aggregate studies

This summer, gravel deposits in the Rural Municipality (RM) of Ste. Rose were mapped as part of an ongoing project to update aggregate information in the province (Groom, GS-22, this volume). The last update of this municipality was done in 1978. Aggregate information is used in municipal development plans, resource management within the MGS, and is available to other government departments and outside clients on request. Also, a pit and quarry inventory of the Icelandic River–Washow Bay watershed area was completed to provide information to the Water Stewardship Department for inclusion in their planning document.

Potash study

Land and mineral rights, as well as surface ownership information, were acquired and compiled into a database for the St-Lazare potash project area. The area of compilation includes the RM of Archie and the RM of Ellice, townships 15 to 18. In addition, digital 1:20 000 data was acquired for both of the rural municipalities and used for GIS mapping and analysis purposes. Thirty-seven road and railway plans were digitized and added to the GIS database. This project is near completion.

Field trips

The Sedimentary and Industrial Minerals Section hosted the 'Lower to Middle Paleozoic Stratigraphy of Southwestern Manitoba' field trip for the MGS this spring. This three-day trip targeted portions of Manitoba's Interlake Silurian and Ordovician stratigraphy and the Devonian in the Lake Winnipegosis area. The highlights of the trip were the salt springs and Mafeking quarry chimneys exposed in the Dawson Bay area (Lake Winnipegosis). Field trips were also conducted for The Manitoba Museum, Brandon University, two petroleum companies and one diamond exploration company. Sites visited included the Mesozoic escarpment, the Paleozoic–Precambrian boundary in southwestern Manitoba and the Cormorant Lake outlier (Silurian–Ordovician). The section also provided advice and staff support to the EdGEO (education geology) program for science teachers at the University of Manitoba Field School at Star Lake in Whiteshell Provincial Park. The program was partially assisted by the Manitoba Geological Survey.

Economic considerations

Large regional syntheses, such as the Williston Basin TGI and lineament compilation projects, are the framework upon which subsequent exploration will be based. The TGI project has shown that interprovincial subsurface correlations are invaluable and represent a significant accomplishment. This is best reflected in the Mesozoic section where cross-border correlations had not previously been attempted. This work is significant for the exploration of shallow gas in southwestern Manitoba.

The discovery of the new Sinclair field (conventional oil) in southwestern Manitoba coincided with the cross-border correlations of the Bakken Formation, Three Forks Group. Industry has benefited from the co-operative mapping project and discussions between Manitoba and Saskatchewan in understanding the dynamics of this

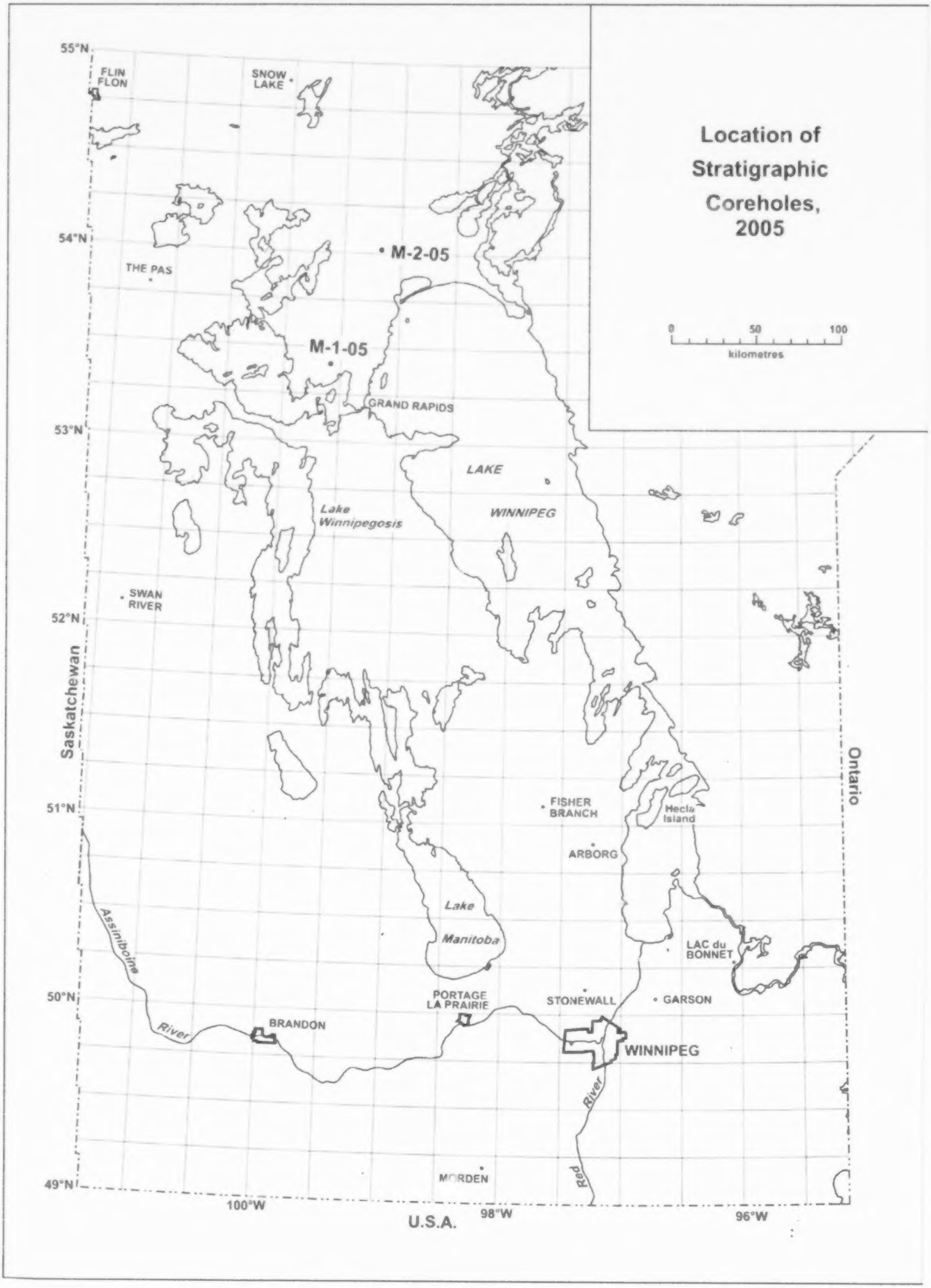
Location of Stratigraphic Coreholes, 2005
0
50
100
kilometres
55°N
54°N
53°N
52°N
51°N
50°N
49°N
100°W
98°W
96°W
FLIN FLON
SNOW LAKE
THE PAS
M-2-05
M-1-05
GRAND RAPIDS
LAKE WINNIPEG
Lake Winnipegosis
SWAN RIVER
Saskatchewan
Ontario
FISHER BRANCH
Hecla Island
ARBORG
Lake Manitoba
LAC du BONNET
Assiniboine River
PORTAGE LA PRAIRIE
STONEWALL
GARSON
BRANDON
WINNIPEG
Red River
MORDEN
U.S.A.

Figure GS-23-2: Location of stratigraphic coreholes, 2005.

exciting new play. Also, the compilation of all oil and gas shows for the TGI project will help the oil and gas industry.

It is hoped that further hydrocarbon and mineral exploration will be conducted in Manitoba as a result of the lineament compilation study and mineral deposit database. Surficial mapping and aggregate studies are important for effective land-use planning, and hydrocarbon, groundwater and industrial minerals development. The potash study is an excellent example of the application of land-use planning to directly assist the industrial minerals industry.

Acknowledgments

The author thanks all staff of the Sedimentary and Industrial Minerals Section who made contributions to this report. They include J. Bamburak, D. Bogdan, H. Groom, G. Keller, P. Leskiw and G. Matile. Thanks also go to M. Nicolas (Petroleum Branch, Manitoba Science, Technology, Energy and Mines) who provided updates to the TGI project. J. Bamburak kindly edited this report.

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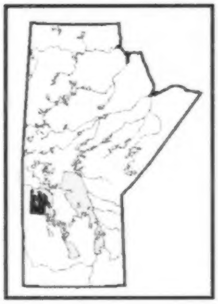
GS-24 Manitoba Geological Survey's Stratigraphic Corehole Drilling Program, 2006 (parts of NTS 62N16 and 63C1)

by J.D. Bamburak

Bamburak, J.D. 2006: Manitoba Geological Survey's stratigraphic corehole drilling program, 2006 (parts of NTS 62N16 and 63C1); *in* Report of Activities 2006, Manitoba Science, Technology, Energy and Mines, Manitoba Geological Survey, p. 246–252.



Summary

Under the 2006 Corehole Drilling Program of the Manitoba Geological Survey (MGS), two stratigraphic coreholes were drilled west of Lake Winnipegosis. Corehole M-1-06, completed to a depth of 75.4 m, confirmed the presence, at surface, of the Devonian Winnipegosis Formation further to the south than previously thought. The hole ended in Devonian Ashern Formation and provided core samples in an area where it had not been previously intersected. Corehole M-2-06 was drilled to 90.7 m into the Winnipegosis Formation and is the deepest and furthest west corehole to be drilled along PR 271.

The area west of Lake Winnipegosis has been indicated as a potential region for Upper Mississippi Valley-type (MVT) mineralization in several studies previously carried out by the MGS. Vertical movements within the Superior Boundary Zone of the Precambrian basement are believed to have induced fracturing in the overlying Paleozoic carbonates providing pathways for metal-rich fluids. Anomalous concentrations of lead, zinc, copper and nickel have been found in previously analyzed drillcore. Split samples from the new holes will be chemically analyzed and the results added to the Survey's Phanerozoic Geochemical Database.

The presence of anomalous mineralization, from previous studies, seems to indicate that MVT mineralization extends southwest of Pemmican Island (in the north basin of Lake Winnipegosis) for over 100 km along the trend of the Superior Boundary Zone. The Pine Point mining district of the Northwest Territories, with its association with the Great Slave Shear Zone, may possibly serve as a model for MVT mineralization in Manitoba.

Introduction

Under the Manitoba Geological Survey (MGS) Corehole Drilling Program conducted in 2006, two coreholes (Figure GS-24-1) were drilled in west-central Manitoba, near Lake Winnipegosis. The coreholes were selected to enhance the Survey's stratigraphic knowledge of the Devonian stratigraphy in an area where carbonate outcrops appear to be very similar and limited drilling has been conducted. According to McCabe and Barchyn (1982), the Devonian sequence, shown from bottom to top in Figure GS-24-2, comprises a series of four complex shallowing-upward shale-carbonate-evaporite cycles:

1) The Elk Point Group, consisting of the basal Ashern Formation overlain by the Winnipegosis/Elm Point Formation and the Prairie Evaporite, is the first, thickest and best defined cycle.
2) The second cycle is represented by five members of the Dawson Bay Formation. The basal member of the cycle is the Second Red Beds overlain by the Lower, Middle and Upper members of the Dawson Bay Formation and the Hubbard Evaporite (now dissolved in Manitoba).
3) The third cycle comprises the Point Wilkins Member of the Souris River Formation, initiated by the First Red Beds. The basal unit is overlain by the Lower, Middle and Upper beds of the Point Wilkins Member and culminating with the Davidson Evaporite (now dissolved in Manitoba).
4) The fourth cycle consists of a basal shale overlain by a carbonate bed within the Sagemace Member of the Souris River Formation. The presence of an evaporite at the top of the member is suspected.

A secondary objective was to provide drillcore samples from the west side of Lake Winnipegosis for the Survey's geochemical database. In 1981, the MGS initiated the chemical analysis of 30 cm intervals of stratigraphic drillcore (Gale et ai., 1981). By 1985, a total of 6301 core samples had been analyzed from 66 coreholes, mainly within the Paleozoic outcrop belt of southwestern Manitoba (Gale and Conley, 2000). The study indicted the potential for 'widespread' Upper Mississippi Valley-type (MVT) mineralization within Paleozoic rock in the vicinity of the buried Precambrian Superior Boundary Zone (SBZ) on the basis of anomalous base-metal values detected west of Lake Winnipegosis. Gale and Conley (2000) documented previous studies that suggested MVT mineralization may have occurred in Manitoba in the following succession:

1) vertical fractures penetrated upwards into the overlying Paleozoic rock due to basement re-activation along the SBZ;
2) basement and interformational fluids used the fractures as pathways, allowing the brines to dissolve out evaporite beds, such as the Prairie Evaporite (Figure GS-24-2);
3) collapse of the overlying stratigraphic units occurred due to the removal of the evaporites;

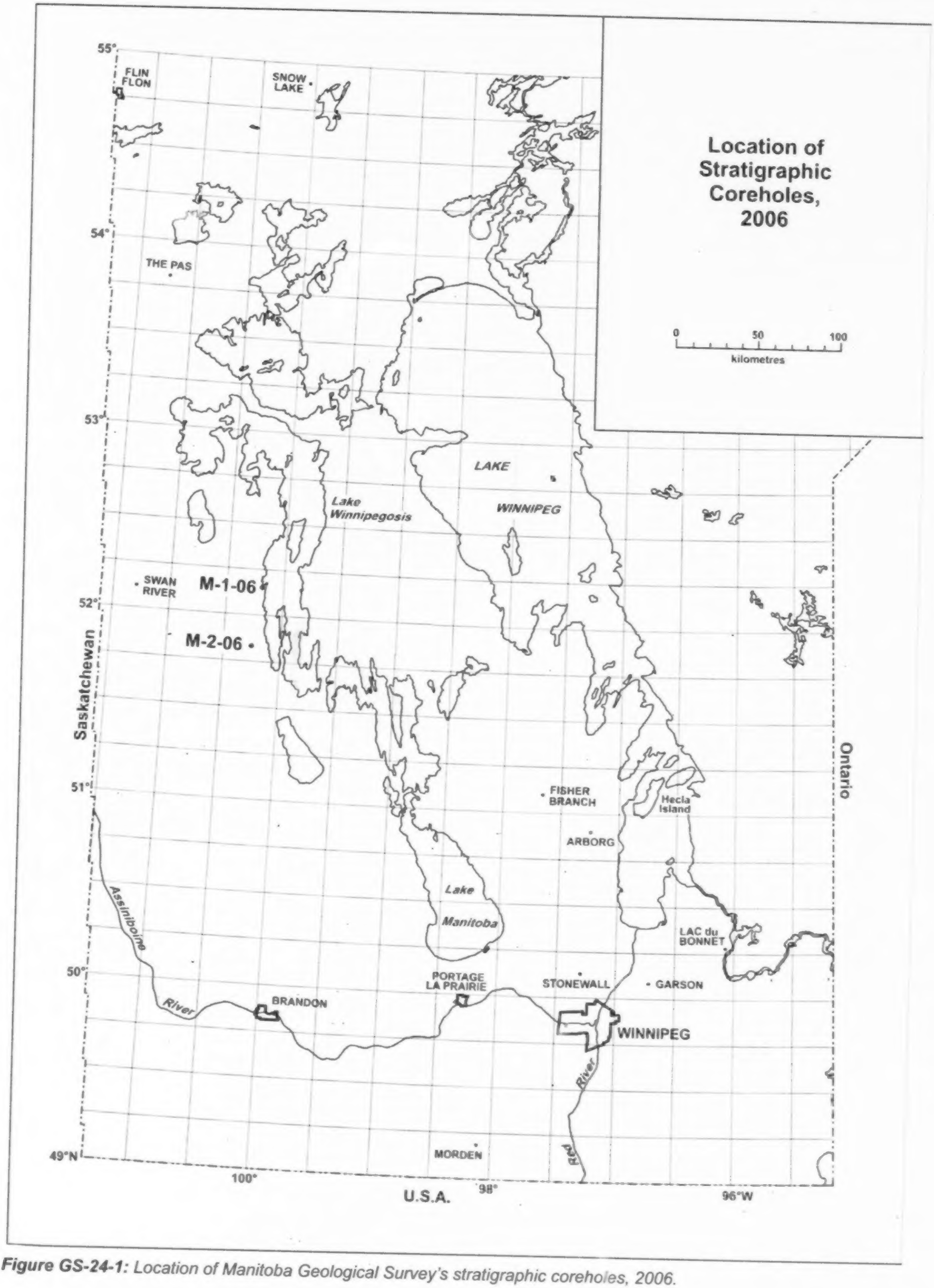
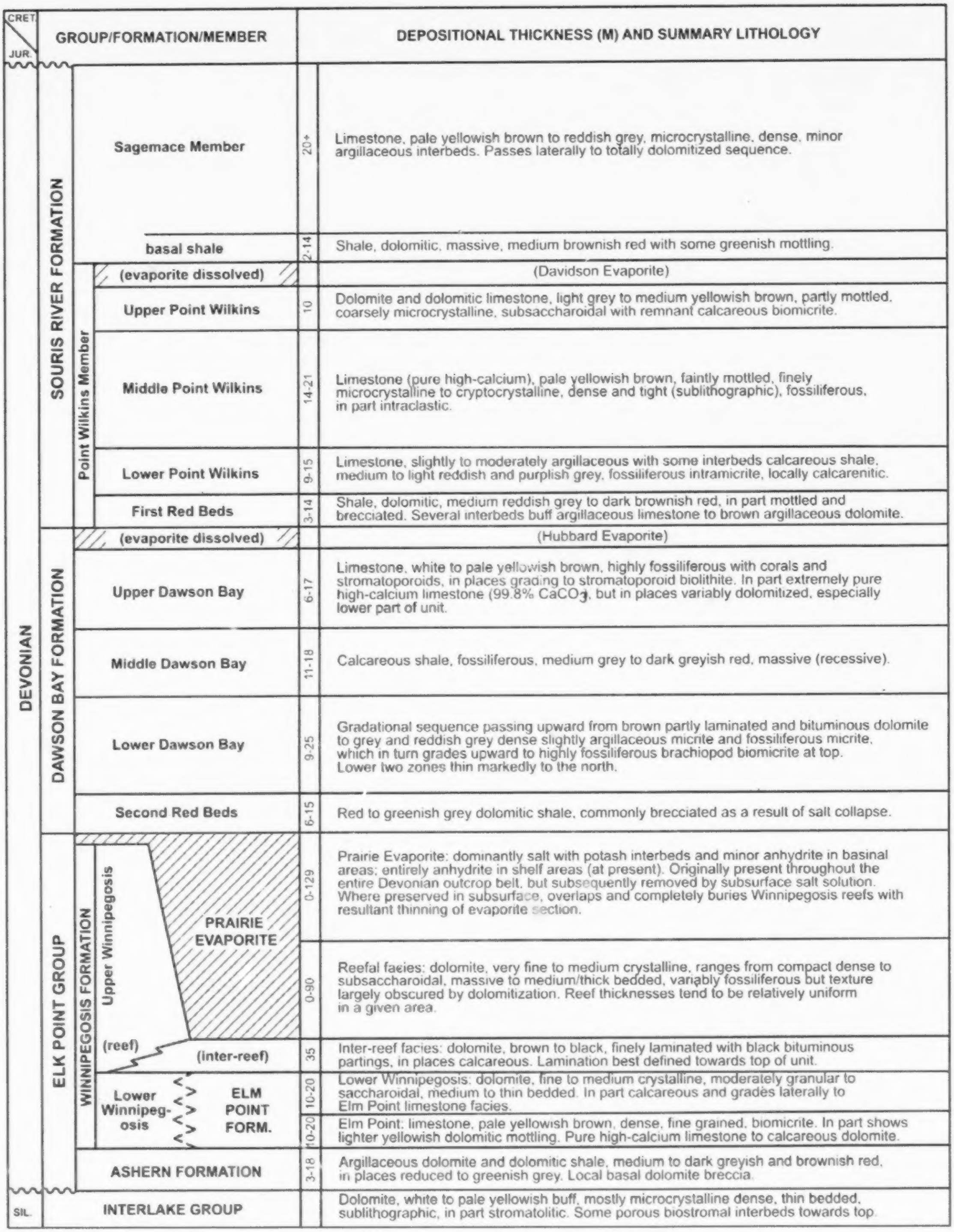

Location of Stratigraphic Coreholes, 2006
0
50
100
kilometres
55°
54°
53°
52°
51°
50°
49°N
100°
98°
96°W
FLIN FLON
SNOW LAKE
THE PAS
SWAN RIVER
M-1-06
M-2-06
Lake Winnipegosis
LAKE WINNIPEG
Saskatchewan
Ontario
U.S.A.
FISHER BRANCH
ARBORG
Hecla Island
Lake Manitoba
LAC du BONNET
PORTAGE LA PRAIRIE
STONEWALL
GARSON
BRANDON
WINNIPEG
Assiniboine River
Red River
MORDEN

Figure GS-24-1: *Location of Manitoba Geological Survey's stratigraphic coreholes, 2006.*



CRET. JUR.	GROUP/FORMATION/MEMBER			DEPOSITIONAL THICKNESS (M) AND SUMMARY LITHOLOGY	
DEVONIAN	SOURIS RIVER FORMATION		**Sagemace Member**	20+	Limestone, pale yellowish brown to reddish grey, microcrystalline, dense, minor argillaceous interbeds. Passes laterally to totally dolomitized sequence.
			basal shale	2-14	Shale, dolomitic, massive, medium brownish red with some greenish mottling.
		Point Wilkins Member	**(evaporite dissolved)**		(Davidson Evaporite)
			Upper Point Wilkins	10	Dolomite and dolomitic limestone, light grey to medium yellowish brown, partly mottled, coarsely microcrystalline, subsaccharoidal with remnant calcareous biomicrite.
			Middle Point Wilkins	14-21	Limestone (pure high-calcium), pale yellowish brown, faintly mottled, finely microcrystalline to cryptocrystalline, dense and tight (sublithographic), fossiliferous, in part intraclastic.
			Lower Point Wilkins	9-15	Limestone, slightly to moderately argillaceous with some interbeds calcareous shale, medium to light reddish and purplish grey, fossiliferous intramicrite, locally calcarenitic.
			First Red Beds	3-14	Shale, dolomitic, medium reddish grey to dark brownish red, in part mottled and brecciated. Several interbeds buff argillaceous limestone to brown argillaceous dolomite.
	DAWSON BAY FORMATION		**(evaporite dissolved)**		(Hubbard Evaporite)
			Upper Dawson Bay	6-17	Limestone, white to pale yellowish brown, highly fossiliferous with corals and stromatoporoids, in places grading to stromatoporoid biolithite. In part extremely pure high-calcium limestone (99.8% CaCO$_3$, but in places variably dolomitized, especially lower part of unit.
			Middle Dawson Bay	11-18	Calcareous shale, fossiliferous, medium grey to dark greyish red, massive (recessive).
			Lower Dawson Bay	9-25	Gradational sequence passing upward from brown partly laminated and bituminous dolomite to grey and reddish grey dense slightly argillaceous micrite and fossiliferous micrite, which in turn grades upward to highly fossiliferous brachiopod biomicrite at top. Lower two zones thin markedly to the north.
			Second Red Beds	6-15	Red to greenish grey dolomitic shale, commonly brecciated as a result of salt collapse.
	ELK POINT GROUP	WINNIPEGOSIS FORMATION	**Upper Winnipegosis** / **PRAIRIE EVAPORITE**	0-129	Prairie Evaporite: dominantly salt with potash interbeds and minor anhydrite in basinal areas; entirely anhydrite in shelf areas (at present). Originally present throughout the entire Devonian outcrop belt, but subsequently removed by subsurface salt solution. Where preserved in subsurface, overlaps and completely buries Winnipegosis reefs with resultant thinning of evaporite section.
			(reef)	0-90	Reefal facies: dolomite, very fine to medium crystalline, ranges from compact dense to subsaccharoidal, massive to medium/thick bedded, variably fossiliferous but texture largely obscured by dolomitization. Reef thicknesses tend to be relatively uniform in a given area.
			(inter-reef)	35	Inter-reef facies: dolomite, brown to black, finely laminated with black bituminous partings, in places calcareous. Lamination best defined towards top of unit.
			Lower Winnipegosis	10-20	Lower Winnipegosis: dolomite, fine to medium crystalline, moderately granular to saccharoidal, medium to thin bedded. In part calcareous and grades laterally to Elm Point limestone facies.
			ELM POINT FORM.	10-20	Elm Point: limestone, pale yellowish brown, dense, fine grained, biomicrite. In part shows lighter yellowish dolomitic mottling. Pure high-calcium limestone to calcareous dolomite.
		ASHERN FORMATION		3-18	Argillaceous dolomite and dolomitic shale, medium to dark greyish and brownish red, in places reduced to greenish grey. Local basal dolomite breccia.
SIL.	**INTERLAKE GROUP**				Dolomite, white to pale yellowish buff, mostly microcrystalline dense, thin bedded, sublithographic, in part stromatolitic. Some porous biostromal interbeds towards top.

Figure GS-24-2: *Detailed Devonian stratigraphic succession and lithology (from McCabe and Barchyn, 1982; Bezys and McCabe, 1996).*

4) continued migration of basement and interformational fluids, some possibly containing metallic sulphides, into fractured and brecciated carbonates; and
5) precipitation of metals in a trap below an unfractured shale aquitard, such as the Ashern Formation (Figure GS-24-2).

Duck Bay

The community of Duck Bay is situated on the west shore of Lake Winnipegosis, approximately 20 km north of Camperville, and on the northern end of PR 272. In 1973, corehole M-8-73 (Figure GS-24-3) was drilled on the southern margin of the community to a depth of 28.9 m. The lack of a distinct marker within the dolomitic interval initially produced difficulties in the regional correlation of the hole according to McCabe (1973). The Winnipegosis Formation designation of the core was only reached with much reservation. To confirm the 1973 interpretation, a deeper corehole was to be drilled in 2006 at the site of corehole M-8-73. However, because of

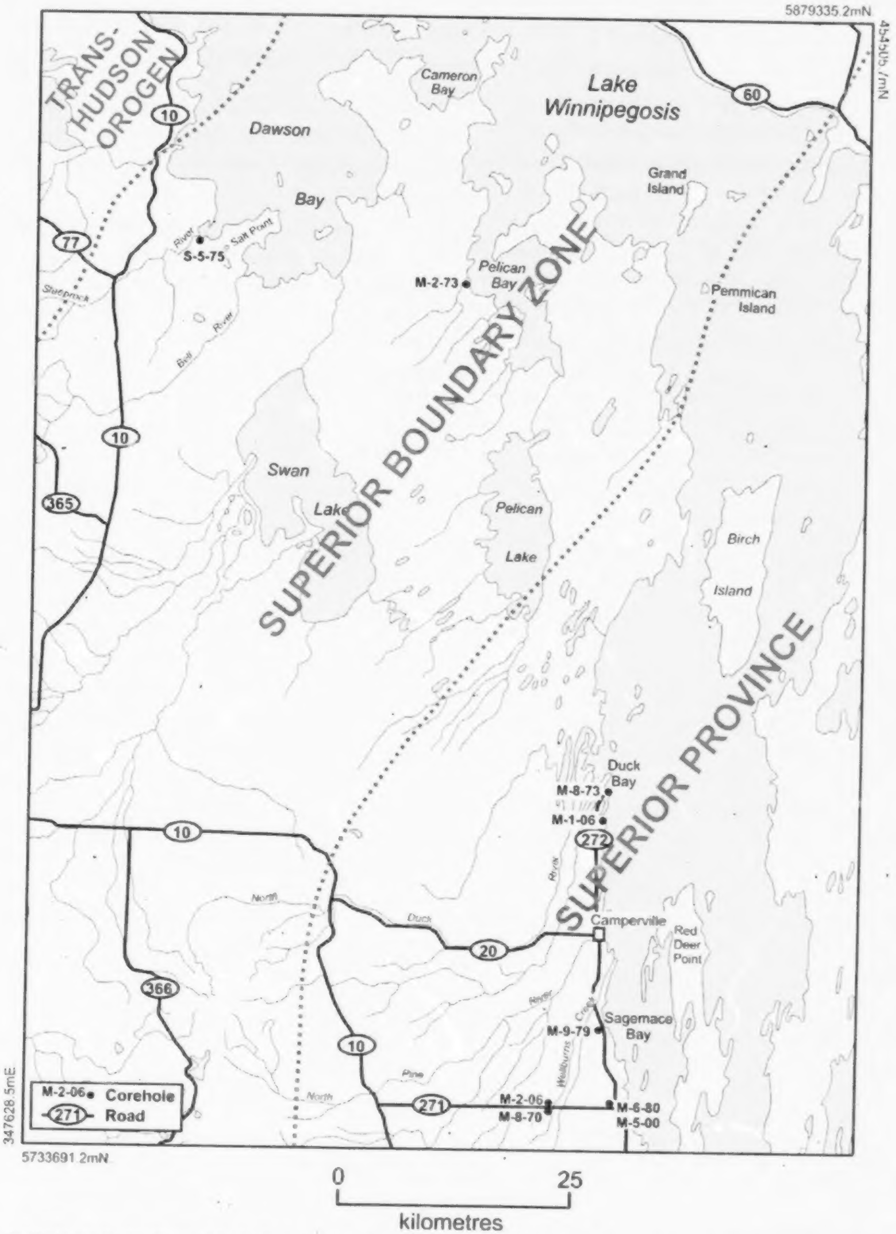

5879335.2mN
454505.7mN
TRANS-HUDSON OROGEN
Cameron Bay
Lake Winnipegosis
Dawson Bay
Salt Point
River
S-5-75
Grand Island
Pelican Bay
M-2-73
Steeprock
Bell River
Pemmican Island
SUPERIOR BOUNDARY ZONE
Swan Lake
Pelican Lake
Birch Island
SUPERIOR PROVINCE
Duck Bay
M-8-73
M-1-06
North
Duck
Camperville
Red Deer Point
River
Creek
Sagemace Bay
M-9-79
Pine
North
Wellburns
M-2-06
M-8-70
M-6-80
M-5-00
10
77
365
366
20
60
271
272
M-2-06 Corehole
271 Road
347628.5mE
5733691.2mN
0
25
kilometres

Figure GS-24-3: Selected stratigraphic holes west of Lake Winnipegosis and the location of Pemmican Island.

surface development since 1973, it was discovered that the previously exposed outcrop was buried beneath overburden and a new drill site was selected in the vicinity of a bedrock quarry situated 5 km to the south.

In early August 2006, corehole M-1-06 (Figure GS-24-1) was completed to a depth of 75.4 m, ending in the Ashern Formation (Figure GS-24-2; Table GS-24-1). The new hole proved that the Winnipegosis Formation not only underlies the community of Duck Bay, but also outcrops at least 5 km further to the south than previously thought. The core from M-1-06 will be split and half of the core will be crushed and sent for instrumental neutron activation analysis (INAA) and inductively couple plasma (ICP) analysis.

Wellburns Creek (formerly Point River)

McCabe and Bannatyne (1970) drilled corehole M-8-70 (Figure GS-24-3) in 1970, south of PR 271, immediately east of a tributary to Wellburns Creek (formerly Point River), west of Lake Winnipegosis. The corehole was drilled with a Winkie drill to a depth of 49.7 m, with poor core recovery (17.7 m). To improve upon the 1970 core recovery and to drill closer to the eastern margin of the SBZ, it was decided in 2006 to drill a deep hole west of the site for corehole M-8-70.

In mid-August 2006, corehole M-2-06 was completed to a depth of 90.7 m, ending in Upper Member of the Winnipegosis Formation (Figure GS-24-3; Table GS-24-1). Although the upper part of the new corehole was broken up and had some missing core, recovery was generally good below 38 m. Pyrite mineralization was noted throughout the corehole and a possible sphalerite/galena grain was noted in a fracture shear within the Second Red Beds of the Dawson Bay Formation at a depth of about 72.8 m. It should be noted that coreholes M-6-80 and M-5-00 (Figure GS-24-3), located at the rehabilitated Pine River Junction quarry, 8 km to the east of corehole M-2-06, both contained sphalerite crystals (Bamburak et al., 2000) and anomalous Zn values within the Winnipegosis Formation (Gale and Conley, 2000; Table GS-24-2).

The presence of Pb-Zn mineralization, if confirmed by INAA/ICP analysis, in corehole M-2-06 would mark the third time that MVT mineralization has been found in drillcore recovered along the eastern end PR 271.

Table GS-24-1: Summary of stratigraphic corehole data, 2006.

Hole no.	Location and elevation (m asl)	SYSTEM/Formation/ (Member)	Interval (m)	Lithology summary
M-1-06 Duck Bay South	12-29-36-19W 5775207N 421140E 258	DEVONIAN/Winnipegosis/ (Upper)	0.0-53.0	Reef facies, dolomite, buff, well defined bedding with massive stromatolites, good to excellent fine vuggy (birdseye) porosity
		(Lower)	53.0-68.0	Platform facies, dolomite, buff, mottled, massive near top, pinpoint porosity near middle, and sand infill near base in caves and vugs
		Ashern	68.0-75.4	Dolomite, argillaceous and shale, greenish and red mottled
M-2-06 Wellburns Creek West	02-04-33-20W 5739363N 415171E 280	DEVONIAN/Souris River/ (Sagemace)	0.0-17.7	Limestone, brown, fine grained with small vugs and shale, calcareous, grey to buff limestone and breccia with black sulphides
		(Point Wilkins)	17.7-26.0	Limestone, yellow and brown, sugary, vuggy
		(First Red Beds)	26.0-35.8	Shale, breccia with disturbed bedding, limestone and dolomite
		Dawson Bay/(Upper)	35.8-51.1	Dolomite, white and brown with shale and limestone
		(Middle)	51.1-63.5	Shale, buff to grey, calcareous shale with brachiopods
		(Lower)	63.5-66.7	Limestone, grey to buff, mottled, brachiopods, calcite filled vugs with fine pyrite
		(Second Red Beds)	66.7-85.1	Polymict collapse breccia, limestone, dolomite with fine pyrite, 72.7 to 72.9 subvertical fracture with 2 mm metallic grain with pryite and sphalerite/galena?
		Winnipegosis/(Transition Zone)	85.1-85.3	Dolomite, buff to grey, massive with stylolites and pyrite blebs
		(Upper)	85.3-90.7	Dolomite, buff, pinpoint porosity and larger in layers, stromatolith banding

Table GS-24-2: Selected copper, zinc, lead and nickel analyses from coreholes drilled in the vicinity of the north basin of Lake Winnipegosis and mean values from 6301 core samples (from Gale and Conley, 2000).

Corehole	Interval (m)	Cu (ppm)	Rank	Zn (ppm)	Rank	Pb (ppm)	Rank	Ni (ppm)	Rank	Formation
M-2-73	9.8–10.2	13	not ranked	27	not ranked	**64**	**4th**	0	not ranked	Dawson Bay
S-5-75	6.3–7.0	20	not ranked	**193**	**4th**	11	not ranked	**57**	**6th**	Dawson Bay
	48.8–49.4	4	not ranked	**162**	**6th**	0	not ranked	8	not ranked	Winnipegosis
M-9-79	30.5–30.8	6	not ranked	15	not ranked	**200**	**1st**	0	not ranked	Winnipegosis
M-6-80	21.0–21.3	7	not ranked	**147**	**7th**	1	not ranked	9	not ranked	Souris River
	52.4–53.1	11	not ranked	14	not ranked	1	not ranked	**49**	**10th**	Souris River
	97.3–97.6	8	not ranked	16	not ranked	1	not ranked	**55**	**7th**	Dawson Bay
	113.0–113.1	3	not ranked	**225**	**3rd**	1	not ranked	21	not ranked	Winnipegosis
	116.9–117.3	**160**	**3rd**	13	not ranked	8	not ranked	29	not ranked	Winnipegosis
Mean of 6301 samples		5.75±7		14.49±4		1.09±5		4.09±3		All
M-5-00*	115.0–116.0	156	n/a	65	n/a	6	n/a	19	n/a	Winnipegosis
	116.0–117.0	410	n/a	38	n/a	5	n/a	32	n/a	Winnipegosis

Notes:

Anomalous geochemical values and their rank within 6301 corehole samples of Gale and Conley (2000) are shown in bold for contrast with typical background and mean values.

* values from M-5-00 postdated the Gale and Conley study

n/a = not applicable

It should also be noted that Gale and Conley (2000) found evidence of MVT mineralization in the 6301 corehole samples they analyzed. The most significant occurrences are discussed below:

- approximately 30 km to the north-northwest of coreholes M-6-80 and M-5-00, the highest Pb value (200 ppm over 0.3 m) was found in corehole M-9-79 within the Winnipegosis Formation (Figure GS-24-3; Table GS-24-2);
- within the SBZ near Pelican Bay and 110 km north-northwest of corehole M-1-06, the fourth highest Pb value (64 ppm over 0.4 m) was found in corehole M-2-73 within the Dawson Bay Formation (Figure GS-24-3; Table GS-24-2); and
- on the western margin of the SBZ and 110 km north-west of corehole M-1-06, the fourth and sixth highest Zn values (193 ppm over 0.7 m and 162 ppm over 0.6 m, respectively) were found in corehole S-5-75 within the Dawson Bay and Winnipegosis formations, respectively (Figure GS-24-3; Table GS-24-2).

Evidence of MVT mineralization was also found by Bamburak and Klyne (2004). A hole drilled off the east shore of Pemmican Island (Figure GS-24-3) in the north basin of Lake Winnipegosis returned values of 4.59% Zn, 0.41% Pb and 0.014% Cu over 15 cm of the Silurian Interlake Group.

The regional dip of Devonian and older Paleozoic formations located between Dawson Bay and Sagemace Bay (Figure GS-24-3) is about 2 m/km to the south-southwest. The anomalous mineralization, described above, is found in Devonian and Silurian formations that are situated within or updip of the SBZ. This may indicate that there is a potential for MVT mineralization, which could extend for over 100 km along and parallel to the trend of the SBZ, in west-central Manitoba.

Pine Point Model

Gale and Conley (2000) suggested that the Pine Point mining district, in the Northwest Territories, could be a possible model for potential MVT mineralization in Manitoba. Pine Point is situated 1300 km northwest of corehole M-1-06, on the south side of the Great Slave Lake Shear Zone (and McDonald Fault). Over 87 Pb-Zn deposits, within karst structures, were defined within a 24 by 65 km area. From these deposits, at least 36 orebodies were mined by Pine Point Mines Ltd. (controlled and operated by Cominco Ltd.). Total production was 64.3 million tonnes averaging 3.4% Pb and 7.0% Zn (Symons et al., 1993). According to Wright et al. (1994), karst development in the Pine Point area was related to basement re-activation that induced fracturing in the dolomite overlying the Great Slave Lake Shear Zone. Deposition of most Pine Point orebodies occurred within a single interconnected paleokarst network where metallic sulphides precipitated from chloride-rich brines (Rhodes et al., 1984).

Economic considerations

Devonian stratigraphic studies not only help to resolve stratigraphic problems, but may also provide a further understanding of metal migration/emplacement in an area where anomalous sequences do exist. It is important that this information is studied and documented to enable the investigation of Manitoba's MVT mineral potential.

Acknowledgments

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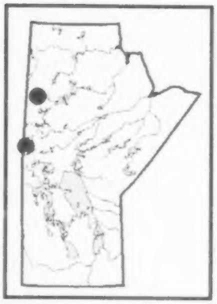
GS-25 Manitoba's Precambrian Drillcore Libraries Program

by D.E. Prouse

Prouse, D.E. 2006: Manitoba's Precambrian Drillcore Libraries Program; *in* Report of Activities 2006, Manitoba Science, Technology, Energy and Mines, Manitoba Geological Survey, p. 253–254.



Summary

Manitoba's Mineral Resources Division has been storing Precambrian drillcore, obtained primarily from exploration drilling, since the early 1970s. Since that time, the Manitoba government has created a substantial repository of drillcore at five locations throughout the province. Funding to help build a significant inventory of drillcore to represent crucial stratigraphy within Manitoba's principal mining districts has been sporadic since the collection was started. Since 2001, funding has been made available to organize drillcore additions from recent years, update core library inventories and conduct some core-retrieval projects.

Introduction

The Manitoba Mineral Resources Division considers the archiving of exploration drillcore to be a valuable data source for use by mineral-exploration companies and researchers. For this reason, the province has retrieved and stored Precambrian drillcore since the early 1970s. The construction of core-storage facilities at The Pas, Thompson and Lynn Lake in the early 1970s provided the necessary space required for the establishment of a comprehensive drillcore collection. A storage facility was acquired in Winnipeg in 1980 to store drillcore from southeastern Manitoba. This acquisition meant that there was now a storage facility for drillcore collected from all of Manitoba's major mining districts.

The Canada-Manitoba Mineral Development Agreement (MDA), which ran from 1984 to 1989, provided funding for activities that were key to strengthening Manitoba's mineral industry, including the Drillcore Libraries Program. During the term of the agreement, significant capital and operating funds allowed for expansion of all northern core-storage facilities and proper documentation and organization of inventories. Once the expansion projects were completed, the four libraries had a combined storage capacity of approximately 330 000 m of core. The libraries contained nearly 180 000 m of core at the end of the MDA in 1989 (Prouse, 1989).

In 1993, the Manitoba Geological Survey established an expediting base at the former Centennial minesite near Flin Flon. The site also provides secure outside storage for drillcore obtained from company exploration programs conducted in the Flin Flon area. The Centennial storage-compound holdings were reorganized and inventoried in 2001.

It is estimated that the Manitoba Geological Survey's Precambrian drillcore libraries currently contain approximately 260 000 m of core. This figure includes about 20 000 m of Precambrian core stored at the department's Midland rock lab in Winnipeg. The estimate does not include core stored at the Centennial site or recent additions to Thompson and Lynn Lake.

How to use Manitoba's drillcore libraries

All five core libraries have lighted, heated inspection rooms with benches, and most have core splitters. **Since the core libraries are not permanently manned, all enquiries and requests for access to any of the northern libraries must be made to**

Dave Prouse, Resident Geologist
Manitoba Geological Survey
Manitoba Science, Technology, Energy and Mines
143 Main Street, Suite 201
Flin Flon, Manitoba R8A 1K2
Telephone: (204) 687-1632
E-mail: dprouse@gov.mb.ca

Access to view core at the Brady Road facility in Winnipeg should be arranged with

Jim Payne, Assessment Geologist
Mines Branch
Manitoba Science, Technology, Energy and Mines
1395 Ellice Avenue, Suite 360
Winnipeg, Manitoba, R3G 3P2
Telephone: (204) 945-6535
Email: jpayne@gov.mb.ca

Once permission has been granted to view nonconfidential core in a specific library, arrangements will be made for the user to obtain keys to that facility. Keys for access to the Centennial compound near Flin Flon can be obtained from the local Manitoba Geological Survey office. Access to the Lynn Lake, Thompson and The Pas libraries must be arranged with the Resident Geologist in Flin Flon.

Companies or individuals wishing to donate and place core in any of Manitoba's northern drillcore libraries must first obtain permission from the Resident Geologist in Flin Flon. In the case of the core library in Winnipeg, permission must be granted from the Assessment Geologist. Core boxes placed in a library will be managed by Manitoba Science, Technology, Energy and Mines personnel. Removal of core boxes from the library premises is not permitted. Users wishing to examine core must be prepared to physically handle the core boxes and return them to their original storage location. Permission is required to sample core contained in any of the province's core libraries. Assay results and pulps from these samples must be forwarded if requested. Quartering of previously sampled drillcore is not permitted except in rare circumstances.

Economic considerations

Diamond drilling of a mineral prospect is the most important and costly phase in the evaluation of any mining property. The preservation of diamond-drill core can help reduce costs of redrilling these prospects as exploration techniques and geological concepts evolve. It also serves as a valuable asset to researchers, especially in areas of extensive overburden or, as in Manitoba's case, where Paleozoic cover rocks overlie Precambrian basement rocks. For these reasons, Manitoba's Mineral Resources Division considers the archiving of exploration drillcore to be a valuable data source.

References

Prouse, D.E. 1989: Manitoba's drill core libraries system; Manitoba Energy and Mines, Minerals Division, Open File Report OF89-4, 44 p.

GS-26

Manitoba Mineral Deposits Database

by T.H. Heine

Heine, T.H. 2006: Manitoba Mineral Deposits Database; *in* Report of Activities 2006, Manitoba Science, Technology, Energy and Mines, Manitoba Geological Survey, p. 255–256.

Summary

Many jurisdictions have established digital databases describing elements of their mineral deposits and occurrences. Not only does such a system provide an inventory of existing deposits, but it also provides a resource for analyzing the potential of a particular geological environment or group of environments for hosting additional resources.

Introduction

Early efforts at establishing an archive of mineral deposits and occurrences consisted of creating a collection of Mineral Inventory Cards (Bamburak, 1980). These summarized the location, work performed, geology and related information for each occurrence. Although this database consisted of paper records, xerographic copies could be obtained from the Geoscience Information Section of the Manitoba Geological Survey in Winnipeg. The Mineral Inventory Cards continue to be widely used, and were maintained until about 1992 (metallic minerals) and 2002 (industrial minerals). Some of the cards can be accessed through the Internet. During this period, the Mineral Deposit Series of publications was published (Manitoba Industry, Trade and Mines, 1988–2003). These had a purpose similar to that of the Mineral Inventory Cards, but concentrated of individual 1:50 000 NTS areas and were distributed as individual reports. They covered only the main mining areas of Manitoba and were current only up to the date of publication. By the 1990s, it became evident that a province-wide digital database that could be updated on a regular basis would provide a valuable resource to the mineral-exploration community. To this end, an effort was put into designing a relational database of the mineral deposits and occurrences in Manitoba.

Existing information

A considerable archive of information about Manitoba's mineral deposits and occurrences has already been compiled in the Mineral Inventory Cards and Mineral Deposit Series. Previous compilations have also described mineral occurrences in the northern Superior Province. In addition, recent changes to *The Mines and Minerals Act* have made available more than 3000 assessment files. These provide additional information on work performed on mineral occurrences that have already been documented, as well as details about new ones. The newly designed database will include a subset of information from the above sources and provide users with a search engine to query the data.

Structure of the database

In order to maintain consistency, the database uses the same occurrence numbers that are used in the Mineral Deposit Series. The prefix for each occurrence number is the 1:50 000 NTS sheet designation, and occurrences are numbered sequentially. The database consists of two series of tables: a set of lookup tables that facilitate data entry and a series of data tables that are linked by a common occurrence-number field. The data tables contain the following information:

- occurrence number
- occurrence location information
- information about gaining access to each occurrence
- geological setting
- deposit type and characteristics of the mineralization
- workings (shafts, pits, trenches)
- commodities of interest at occurrence
- rock type(s) associated with, and minerals constituting the mineralization
- alteration associated with the mineralization
- geophysical, geochemical and other surveys undertaken at the occurrence
- diamond drilling
- publications and assessment files that relate to the occurrence

Some of the fields are linked to data already available on Manitoba government websites. For example, non-confidential assessment files can be viewed through the GIS Map Gallery at <http://www.gov.mb.ca/iedm/mrd/geo/gis/index.html>.

The database is being developed in Oracle®, and current plans call for it to be issued in 2008 as a CD-ROM. Updates will be released as they become available. The structure of the database has been finalized and is currently being tested.

Economic considerations

Electronic databases provide a powerful tool that allow the rapid analysis of large quantities of data. Organizations can quickly see and evaluate what work has been undertaken in an area, in order to optimize their mineral-exploration efforts.

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PUBLICATIONS

PRELIMINARY MAPS

PMAP2006-1	Geology of the Schist Lake–Mandy mines area, Flin Flon, Manitoba (parts of NTS 63K12) by R.-L. Simard	scale 1:5 000
PMAP2006-2	Bedrock geology of the Bear Lake area, Manitoba (parts of NTS 53M4 and 63P1) by C.O. Böhm and R.P. Hartlaub	scale 1:50 000
PMAP2006-3	Revised geology of the Wuskwatim–Threepoint lakes area, Manitoba (NTS 63O10 and parts of 63O11) by H.V. Zwanzig, J.A. Percival and L. Murphy	scale 1:50 000
PMAP2006-4	Bedrock geology of the Kasmere Lake area, Manitoba (NTS 64N11 and parts of NTS 64N6) by C.O. Böhm and S.D. Anderson	scale 1:50 000
PMAP2006-5	Bedrock geology of the Putahow Lake area, Manitoba (NTS 64N15) by S.D. Anderson and C.O. Böhm	scale 1:50 000
PMAP2006-6	Surficial geology of the Kasmere–Putahow lakes area, northwestern Manitoba (parts of NTS 64N10, 11, 14 and 15) by G.L.D. Matile	scale 1:50 000
PMAP2006-7	Geology and structure of the Garner Lake–Gem Lake area, Rice Lake greenstone belt, Manitoba (NTS 52L11 and 14) by-S.D. Anderson	scale 1:20 000
PMAP2006-8	Geology of the east-central part of the Bird River area, Manitoba (NTS 52L6N) by H.P. Gilbert	scale 1:20 000
PMAP2006-9	Geology of the Bernic Lake area around the Tanco mine, Bird River greenstone belt, southeastern Manitoba (NTS 52L6) by P.D. Kremer and S. Lin	scale 1:10 000
PMAP2006-10	Geology of the Bird River Sill, southeastern Manitoba (part of NTS 52L5) by C.A. Mealin	scale 1:5 000

PUBLICATIONS RELEASED NOVEMBER 2005 TO NOVEMBER 2006

Manitoba Geological Survey Reports and Maps

Geoscientific Reports

GR2006-1

Geology of the Thompson Bay–Persian Lake area, North Arm, Athapapuskow Lake, Manitoba (NTS 63K12NE) / by D.E. Prouse

Open File Reports

OF2005-1

Geology of the Hidden Formation on the west limb of the Hidden syncline north of the Railway Fault, Flin Flon, Manitoba and Saskatchewan (part of NTS 63K13SW) / by M. DeWolfe (scale 1:1 000)

OF2005-2

Till geochemistry in northwestern Manitoba (NTS 63N, 64B, 64F and 64G and parts of 63K, 63O, 64A and 64C) / by P.G. Lenton and C.A. Kaszycki (PDF, EXCEL® and Shape files on CD-ROM)

OF2005-3 (Supercedes OF93-4)

Manitoba Geochronology Database / by Manitoba Geological Survey (Digital web release only)

OF2006-1

Humus sampling in the Mayville Igneous Complex, southeastern Manitoba (NTS 52L12): using the mobility of palladium in aqueous surficial environments as a guide to nickel–copper–platinum group element mineralization / by P. Theyer

OF2006-2 to OF2006-29

High-resolution aeromagnetic-residual-total-field and first-vertical-derivative of the magnetic field maps, Wuskwatim Lake area, northern Manitoba (NTS 63 J/10, 63 J/15, 64 O/01, 63 O/02, 63 O/06, 63 O/07, 63 O/08, 63 O/09, 63 O/10, 63 O/15, 63 O/16, 63 P/12, 63 P/13, 64 B/01) / by M. Coyle and F. Kiss

OF2006-30

GIS compilation of geology and tectonostratigraphic assemblages, western Uchi Subprovince, western Superior Province, Ontario and Manitoba / by D.R. Lemkow, M. Sanborn-Barrie, A.H. Bailes, J.A. Percival, N. Rogers, T. Skulski, S.D. Anderson, K.Y. Tomlinson, V. McNicoll, J.R. Parker, J.B. Whalen, P. Hollings and M. Young (1 CD-ROM)

OF2006-31

Reinterpretation of Falconbridge Limited drillcore from the southern part of the exposed Thompson Nickel Belt, Manitoba (parts of NTS 63J, O, P and 64A) / by C.R. McGregor, J.J. Macek and H.V. Zwanzig (1 DVD)

Geoscientific Maps

MAP2006-1

Aggregate resources in the Rural Municipality of Grahamdale, Manitoba / by H.D. Groom (scale 1:100 000)

Preliminary Maps

PMAP2005-1

Geology and structure of the Rice Lake area, Rice Lake greenstone belt, Manitoba (part of NTS 52M4 and 52L13) / by S.D. Anderson (scale 1:20 000)

PMAP2005-2

Bedrock geology of north and central Wintering Lake, Manitoba (parts of NTS 63P5 and 12) / by C.O. Böhm (scale 1:25 000)

PMAP2005-3

Bedrock geology of Nejanilini Lake, Manitoba (parts of NTS 64P5, 12 and 13) / by S.D. Anderson and C.O. Böhm (scale 1:35 000)

PMAP2005-4

Quaternary geology of Nejanilini Lake, Manitoba (parts of NTS 64P5, 12 and 13) / by G.L.D. Matile (scale 1:35 000)

PMAP2005-5

Structural geology of the Mystery–Apussigamasi lakes area, Manitoba (parts of NTS 63P13 and 14) / by Y. D. Kuiper (scale 1:35 000)

PMAP2005-6

Geology of the Bernic Lake Formation, Tanco mine area, southeastern Manitoba (part of NTS 52L6) / by P.D. Kremer (scale 1:10 000)

PMAP2005-7

Geology of the Bird River area, southeastern Manitoba (part of NTS 52L5 and 6) / by M. Duguet (scale 1:50 000)

PMAP2005-8

Geology of the Chrome Property, Bird River Sill, southeastern Manitoba (part of NTS 52L5) / by C. Mealin (scale 1:5 000)

Report of Activities 2005

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FLIN FLON-SNOW LAKE

GS-1

Physical description of the Bomber, 1920 and Newcor members of the Hidden formation, Flin Flon, Manitoba (NTS 63K16SW) / by Y.M. DeWolfe and H.L. Gibson, p. 7-19.

GS-2

Gold metallogenesis and tectonometamorphic history of selected deposits from the Snow Lake area and the southern flank of the Kisseynew Domain, west-central Manitoba (NTS 63J13, 63K10, 63K16 and 63N2) / by S. Gagné, C.J. Beaumont-Smith, A. Hynes and A.E. Williams-Jones, p. 20-27.

GS-3 Manitoba's Precambrian Drillcore Libraries Program / by D.E. Prouse. p. 28-29.

GS-4 Activities of the Manitoba Geological Survey's Flin Flon regional office / by T.H. Heine, p. 30-31.

SUPERIOR BOUNDARY ZONE, THOMPSON NICKEL BELT

GS-5

Bedrock geology of northern and central Wintering Lake, Manitoba (parts of NTS 63P5 and 12) / by C.O. Böhm, p. 32-39.

GS-6

Geochemistry, Sm-Nd isotope data and age constraints of the Bah Lake assemblage, Thompson Nickel Belt and Kisseynew Domain margin: relation to Thompson-type ultramafic bodies and a tectonic model (NTS 63J, O and P) / by H.V. Zwanzig, p. 40-53.

GS-7

Northwestern Superior craton margin, Manitoba: an overview of Archean and Proterozoic episodes of crustal growth, erosion and orogenesis (parts of NTS 54D and 64A) / by R.P. Hartlaub, C.O. Böhm, L.M. Heaman, and A. Simonetti, p. 54-60.

GS-8

Structural geology of the Mystery-Apussigamasi lakes area, Manitoba (parts of NTS 63P13 and 14) / by Y.D. Kuiper, C.O. Böhm and S. Lin, p. 61-68.

GS-9

Pikwitonei–Snow Lake Manitoba transect (parts of NTS 63J, 63O and 63P), Trans-Hudson Orogen–Superior Margin Metallotect Project: new results and tectonic interpretation / by J.A. Percival, J.B. Whalen and N. Rayner, p. 69-91.

FAR NORTH

GS-10

Bedrock and surficial geological field investigations in the Nejanilini Lake area, northern Manitoba (parts of NTS 64P5, 12 and 13) / by S.D. Anderson, C.O. Böhm and G.L.D. Matile, p. 92-103.

SOUTHEASTERN MANITOBA

GS-11

Preliminary results and economic significance of geological mapping in the Gem Lake area, southeastern Rice Lake belt, Manitoba (NTS 52L11 and 14), with emphasis on the Neoarchean Gem assemblage / by S.D. Anderson, p. 104-116.

GS-12

Preliminary results of geological mapping and structural analysis of the Bird River greenstone belt, southeastern Manitoba (NTS 52L5 and 6) / by M. Duguet, S. Lin, H.P. Gilbert and M.T. Corkery, p. 117-124.

GS-13

Geological investigations in the Bird River area, southeastern Manitoba (parts of NTS 52L5N and 6N) / by H.P. Gilbert, p. 125139.

GS-14

Preliminary results from geological mapping of the Bernic Lake Formation, Bird River greenstone belt, southeastern Manitoba (NTS 52L6) / by P.D. Kremer, p. 140-145.

GS-15

Geological investigations of the Chrome property, Bird River Sill, southeastern Manitoba (NTS 52L5) / by C.A. Mealin, p. 146-149.

GS-16

Platinum group element dispersion patterns in humus samples of the Mayville Igneous Complex, southeastern Manitoba (NTS 52L12): survey results and interpretation / by P. Theyer, p. 150-155.

GS-17

Geology, structure and mineralization of the Ore Fault property, Bird River greenstone belt, southeastern Manitoba (parts of NTS 52L5NE and 52L6NW) / by L.A. Murphy and P. Theyer, p. 156-160.

GS-18

Sulphide fragments in waste rock at the Maskwa open pit mine, southeastern Manitoba (NTS 52L6NW): investigations on petrogenesis, potential source rocks and mode of emplacement / by A.E. Stansell and P. Theyer, p. 161-163.

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Phytoremediation and revegetation of mine tailings and bio-ore production: effects of paper mill sludge on plant growth in tailings from Central Manitoba (Au) minesite (NTS 52L13) / by S. Renault and S. Green, p. 167-169.

SOUTHWESTERN MANITOBA

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Aggregate resources in the rural municipalities of Riverside and Turtle Mountain, southwestern Manitoba (NTS 62G3, 4, 5, 6 and 12) / by H.D. Groom, p. 170-175.

MANITOBA GENERAL

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Announcing the new Manitoba Geochronology Database / by A.H. Bailes, G.R. Keller, C.O. Böhm and P.G. Lenton, p. 45.

An appraisal of the potential for volcanic-hosted massive sulphide (VHMS) deposits in the Archean Rice Lake greenstone belt, southeastern Manitoba / by S.D. Anderson, p. 45.

Archean crustal evolution in the northwestern Superior Province in Manitoba and northwestern Ontario and implications for gold metallogeny / by M.T. Corkery, T. Skulski, J.B. Whalen, S. Lin, D. Stone, C.O. Böhm and D.W. Davis, p. 46.

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